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Alternative Energy Generation in Public Health Facilities (Hospitals): An analysis of the coal-fired to the natural gas-fired central generating system

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Alternative Energy Generation in Public Health Facilities (Hospitals): An analysis of the coal-fired to the natural gas-fired central generating system.

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A research report submitted to the Faculty of Engineering and the Built Environment at the University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Architecture (Sustainable and Energy Efficient Cities).

Feb 2025

Declaration

I declare that this research report is my own work except where otherwise acknowledged through referencing. This research report is being submitted to the University of the Witwatersrand, Johannesburg, for the degree of Master of Architecture in Sustainable and Energy Efficient Cities (SEEC). It has not been which has not been previously submitted for any degree or qualification at any institution. I understand the implication of unethical academic behaviour, which comprises plagiarism which is a serious transgression by the University, and the university can institute disciplinary action against.

Abstract

Coal boilers have historically been a significant source of energy generation in industries. However, their use is associated with substantial environmental impacts that are increasingly untenable in the context of climate change. This research examines the challenges and opportunities associated with transitioning from coal-fired to natural gas-fired central generating systems at Helen Joseph Hospital. The researcher chose to focus on natural gas because it is a cleaner and more efficient alternative to coal, making it a viable transitional energy source for decarbonisation in hospital central generating systems. Natural gas functions as a transitional or “bridge” fuel in the global energy landscape. Its relatively lower carbon intensity compared to coal positions it as an intermediate solution that facilitates a gradual shift toward renewable energy sources. This role is critical in mitigating greenhouse gas emissions in the short to medium term, thereby contributing to environmental sustainability and the reduction of public health risks associated with air pollution. The research looks at the low adoption of alternative energy sources in these systems despite their critical role in supporting essential functions such as heating, ventilation, sterilisation, water, and heating. By focusing on energy transition and decarbonisation, the study aims to identify barriers to adoption and propose strategies for implementing more sustainable energy solutions within healthcare facilities, which are among the highest energy consumers in the built environment and are categorised as part of the commercial sector.

Focusing on energy transition and decarbonisation, this study employs a case study approach centred on the Helen Joseph Hospital central generating system. Primary data was gathered through 15 in-depth interviews with purposefully selected key informants. The research methodology used qualitative approaches. The interview data were thematically coded and analysed to address the research questions effectively.

The findings stress the importance of a multi-faceted, collaborative approach to improve the transition from coal-fired boilers to gas-fired systems in hospitals, with a strong emphasis on minimizing environmental impacts. The study highlights that calculating an organisation's carbon footprint, including emissions from boiler operations, can pinpoint opportunities for energy transition and emissions reduction. Additionally, this approach allows for progress tracking over time and contributes to achieving broader sustainability goals.

Key words: coal boiler, natural-gas boiler, energy transition, decarbonisation, GHG emissions, environmental impacts.

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List of abbreviations

CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide Equivalent
COJ	City of Johannesburg Metropolitan Municipality
COT	City of Tshwane Metropolitan Municipality
DID	Gauteng Department of Infrastructure Development
DOH	Gauteng Department of Health
DMRE	Department of Mineral resources and Energy
DNI	Direct Normal Irradiation
DPWI	Department of Public Works and Infrastructure
GHG	Greenhouse gases
GJ	Gigajoule
HVAC	Heating, Ventilation, and Air Conditioning
IREREP	Integrated Renewable Energy Resource Efficiency Programme
kg/h	Kilogram Per Hour
KPa	Kilopascal
kWh	kilowatt-hour
LFO	Light Fuel Oil
LPG	Liquefied Petroleum Gas
NEMA	National Environmental Management Act No. 107 of 1998
NO_X	Nitrogen Oxides
PJ/a	Petajoules per annum
REIPPP	Renewable Independent Power Producer Programme
SO_2	Sulfur dioxide
VOC	Volatile Organic Compounds

CHAPTER 1: BACKGROUND AND CONTEXTUALISATION OF THE STUDY

1.1 Introduction

Buildings are increasingly required to meet higher performance standards in response to the global drive towards decarbonizing the built environment (Kolokotsa et al.,2011). They are expected to be sustainable, reach net zero, foster a healthy and comfortable environment for the occupants and be completely off the grid (Kolokotsa et al., 2011). The desire to achieve net zero buildings is growing due to climate change, increasing energy prices, and the scarcity of fossil fuels in South Africa. More recently, the Paris Agreement calls upon countries to take ambitious action to address climate change by reducing greenhouse gas emissions and adapting to its impacts (Strambo, Burton, and Atteridge, 2019). The country needs to contribute to the global effort to move to net-zero carbon emission by 2050 (RSA, Low Emission Development Strategy, 2020), which is termed the "just transition". The 'Just Transition' is a framework that aims to ensure environmental sustainability by shifting to a green economy that accelerates sustainable energy transitions, job creation, and an inclusive society (RSA, Low Emission Development Strategy, 2020).

South Africa relies significantly on coal to generate 92% of its electricity and the electricity needed to produce approximately 20% of its fuels, including oils, chemicals, and gases (Strambo et al., 2019). This suggests that electricity generation and fuel generation account for most of the emissions. Coal is also one of South Africa's most significant exports by value, accounting for ZAR 61 billion annually (Strambo et al., 2019). Although this is the case, renewable energy has been introduced in many sectors, including energy generation.

South Africa's public health care facilities (hospitals) are among the largest consumers of energy through the generation of steam, which is used mainly for heating, ventilation, cooking, sterilisation, and water heating systems, which are very important for the health of patients (Hohne, Kusakana, and Numbi, 2020). This energy is generated through the central generating system, which operates as a boiler system that utilises coal or natural gas. The average energy consumption ranges from 43–92 kWh/bed/day (Hohne et al., 2020). This system is expected to generate electricity for 24 hrs each day; this, therefore, poses a challenge to the energy

generation and the energy consumption of the health institutions as the demand is exceptionally high.

There are many possible ways of reducing hospitals' energy consumption and decreasing reliance on the central generating system but understanding steam's role in hospitals needs to be assessed (Hohne et al., 2020). According to Porto (2020), steam is used as a sterile medium for air moisturisation, autoclaves, space and water heating, kitchen boilers, and laundry. Much energy is required to generate steam from a coal boiler. Approximately 80% is used for heat to produce steam and 20% for the feed water to the boiling point (Hohne et al., 2020). This shows that steam plays a vital role in providing quality health but is also the highest energy consumer.

1.2 Background of Steam Use in Hospitals

Public health facilities produce steam using boilers, which utilize heat from an external source, in most cases coal or natural gas (compressed natural gas or liquified natural gas) to boil the water and transform it into steam, which is used in the hospital (Porto, 2020). The most inefficient challenge of generating steam using the central generating system is that there is energy loss in the system and emissions from burning coal on site, which poses a health hazard to patients (Porto, 2020). These are among the key reasons why steam generation using coal boilers is not the most energy-efficient means for use in the hospital, even though it has a vital role to play in providing sterilisation and humidification.

Part of the critical uses of steam is the HVAC system mostly in European countries, which is said to ensure indoor thermal comfort for building users (Porto, 2020). During the winter, when the outdoor air is cold and moist, the heating coil of the HVAC needs to raise the incoming temperature. This process reduces the moisture content of the air and provides the required humidity levels. The humidity levels are generally described by the relative humidity percentage, which represents the amount of water vapor held in the air at a specific temperature at any time. Many authors believe that, for health, safety, and comfort reasons, it is necessary to maintain air humidity levels within a determined range to reduce air bacteria (Arundel et al., 2018:12, cited in Porto,2020). Although other studies show that there is a lack of experimental evidence to give the base to these claims) (Porto, 2020).

1.3 Introduction to the Trias Energetica model

Hospitals need to reduce the environmental impact of their buildings, as one of their daily goals is to provide a healing environment for their patients (Kras, 2011). Guenther (2008:378, cited in Kras, 2011:45) describes a range of strategies to reduce the carbon footprint of a building (Kras, 2011). To achieve a carbon-neutral hospital, coordination is required at a greater scale among users, policymakers, designers, and operators (Kras, 2011). Sustainability can be achieved by employing energy efficiency measures and renewable resources cost-effectively (Kras, 2011). The Trias Energetica (Entrop & Brouwers, 2009) is among the oldest and most original sustainability triads that are used to promote the sustainability of buildings. This method was introduced as a three-way strategy for sustainable energy under the so-called 'Trias Energica' (Entrop & Brouwers, 2009). The Model suggests that buildings must have:

1. A continuing improvement in energy efficiency,
2. A more prominent use of sustainable energy sources, and
3. Efficient use of remaining fossil fuels

This model is an ideal approach for hospitals to use to effectively improve the current inefficient status core of public sector hospitals. Figure 1. Shows the 'Trias Energica' model to achieve sustainability in hospital buildings.

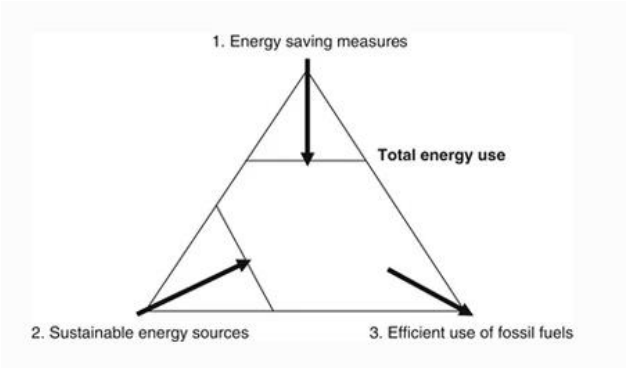


Figure 1: Trias Energetica' – Building Design approaches, source: (Entrop & Brouwers, 2009)

1.4 Supply of alternative energy and Renewable energy to the hospital

Public hospitals do not operate as businesses, as they form part of social infrastructure. However, they need valid energy business cases to decrease their energy costs. Hospitals consume more energy than any other ordinary building because they operate 24 hours daily (Sithole, 2016). As argued, for hospitals to become sustainable, they need to introduce renewable energy and or alternative energy as a source of energy generation, which will completely replace the central energy generating system (Sithole, 2016). Public hospitals have not fully considered solar panels, hydropower, wind turbines, natural gas, etc., as an alternative energy source because of the scepticism about the 'fairly new' technology and the frequent power outages from utilities, which cause uncertainty (Mac-Kinnon, 2018). Renewable energy sources depend on natural conditions for energy generation and generation time. However, to reduce the effects of their intermittent generation, the concept of energy storage and supply back to the grid needs to be more prominent (Weimann and Patel, 2017).

1.5 Problem Statement

Hospitals rank as the second-highest energy consumers within the built environment and are classified as part of the commercial sector (Hohne et al., 2020). Most public hospitals depend on a centralised boiler system to generate steam, which is then distributed to various functional units, including heating, ventilation, and cooling, sterilisation, water heating, and cooking. The remainder of the hospital's energy needs, such as lighting, therapy equipment, and general utilities, are supplied directly by Eskom, which is critical for maintaining uninterrupted hospital operations (Cunningham, 2015).

In many state-owned and provincial hospitals, boilers represent the largest single source of energy consumption. Historically, the centralised supply of heat was considered highly efficient, and many hospitals continue to operate coal-fired boilers running 24 hours a day (Cunningham, 2015). However, advancements in energy technology suggest there are now more efficient and sustainable methods of energy generation for health facilities.

The boilers used in many hospitals utilise a coal grate feed system, requiring manual operation by boiler staff to shovel coal into the furnace. These systems are labour-intensive and emit pollutants such as carbon monoxide and carbon dioxide within hospital premises. Additionally, they necessitate ash and soot disposal, which must comply with the National Environmental Management Act (NEMA) 107 of 1998 (Cunningham, 2015).

Even though renewable energy such as solar and wind offer the cleanest alternative in energy generation, natural gas offers a notably more reliable energy solution (Hassan et al., 2023). The reliability is crucial for the centralised energy generation in settings where uninterrupted power is essential such as the hospital. Centralised energy generation plants are also required to meet real-time fluctuations in energy demand this is called dispatchability (Hassan et al., 2023). Dispatchability ensures a continuous and stable energy output, a feature that variable renewable energy sources such as solar and wind which are subject to weather conditions cannot consistently provide without significant storage.

The research focus of coal-to-gas conversion emanates from the immediate and practical benefits of reducing carbon emissions while maintaining reliable and cost-effective energy supply in hospitals. It reflects the technological landscape and the need for feasible, scalable solutions in the short to medium term, even as the longer-term goal is to transition to fully renewable systems.

1.6 Research aims and objectives.

The aim of the study is to analyse the possibility of transition from coal-fired to natural gas-fired central energy generation systems in public health facilities at Helen Joseph Hospital, focusing on environmental, economic, and operational issues. The study seeks to evaluate the feasibility and effect of adopting natural gas as a cleaner and more efficient energy source for the central generating system.

The objectives of the study are to:

- Examine the existing reliance on coal-fired central generating systems in public health facilities.

- Compare the environmental implications of coal-fired and natural gas-fired systems, including emissions of pollutants such as carbon dioxide (CO_2) and other greenhouse gases, and their compliance with environmental regulations like the National Environmental Management Act (NEMA) 107 of 1998.
- Identify technical, financial, and institutional barriers hindering the adoption of natural gas and alternative energy systems in public health facilities.
- Propose recommendations for transitioning to natural gas-fired systems, including strategies to improve adoption rates, ensure regulatory compliance, and maximise operational efficiency.

1.7 Research Questions

1.7.1 Main Question

How can public health facilities transition from coal-fired to natural gas-fired central generating systems to improve energy efficiency, reduce environmental impact, and ensure sustainable and reliable energy generation?

1.7.2 Sub- Questions

- What technical and institutional barriers exist in the transition to natural gas-fired systems at Helen Joseph Hospital and how can these barriers be addressed to encourage adoption?
- What are the operational inefficiencies, environmental impacts, and energy outputs of existing coal-fired central generating systems in public health facilities?
- How can transitioning to natural gas-fired systems contribute to the long-term sustainability of public health facilities?

1.8 Limitations of the Study

The limitations and problems of carrying out the investigation should not be concealed and ignored (Brink et al ,2013). The limitations are shortcomings, conditions or influences that cannot be controlled by the researcher that place restrictions on the researcher's methodology and conclusions (Brink et al ,2013). This study has been intentionally limited to the examination of

natural gas, however research is required to further explore the possibility of central generating systems using renewable energy technologies and to rigorously test their capabilities. The limitations of the study include the energy consumption data of the healthcare institutions which is recorded manually and therefore the typical energy usage spectrum is unclear including the energy baseline. The data used in this research report for boiler information is historical data obtained from the manual log sheets which were recorded by the boiler operating personnel of the chosen hospital. The manual log sheets can provide valuable insights for research and analysis, the lack of digitisation for reliability raises concerns about data quality and accuracy. The boilers which are analysed in this research report are of different ages even though are of the same capacity. It is mentioned that these boilers' operations and maintenance schedules are different. Another limitation of the study is that it focuses on a single case study, which restricts the ability to generalise the findings to all hospitals in South Africa. While the insights gained are valuable for understanding the specific context of the selected facility, broader applicability may require additional studies across multiple hospitals with varying operational and environmental conditions.

1.9 Structure and outline of the study

This research report comprises six chapters, and **Chapter 1** provides an overview for the research by presenting a clear and comprehensive introduction to the study, establishing the rationale, problem statement, research question, objectives, and limitations. It is a foundation for understanding the research context and guiding the reader through the research report.

Chapter 2 of the research report focuses on reviewing existing literature related to several key themes: the state of energy in South Africa, the concept of decarbonisation, alternative energy generation in public hospitals, the global energy transition, the potential of alternative energy, and the operations of coal boilers in hospitals as an opportunity to implement alternative and renewable energy sources. This chapter also outlines the energy requirements of the hospital while emphasizing the growing need to transition away from fossil fuels and towards sustainable energy solutions. It discusses the opportunities and challenges associated with alternative energy sources such as Natural gas.

Chapter 3 of the research report outlines the approach, methods, and tools used for data collection and analysis to address the research question, “How can public health facilities transition from coal-fired to natural gas-fired central generating systems to improve energy efficiency, reduce environmental impact, and ensure sustainable and reliable energy generation?"

The chapter further discusses the key primary data collection method, in-depth interviews with 15 purposefully selected technical staff. The discussion outlines the data that was required per sub-question as well as the overall findings in relation to the research question**.**

Chapter 4 of the research report presents the findings from primary and secondary data collection intending to understand factors contributing to the low adoption of natural in central generating systems. The data presented is derived from in-person and online interviews, allowing for a comprehensive exploration of the topic. Additionally, data from the technical team, including chief engineers, chief artisans, and boiler operators, supplemented the interview findings.

Chapter 5 This chapter provides a qualitative data analysis organised under the emerging themes. These themes were discussed in relation to the research question and sub-questions. The analysis focused on the environmental effects, cost analysis of alternative energy, and the drive to decarbonising public institutions.

Chapter 6 presents the overall findings on the research question and draws conclusions of the study. This is followed by recommendations for further research in this field, especially in relation to the limitations highlighted in Section 1.8 of this report. Further research work needs to be conducted to address the energy consumption data of the healthcare institutions which is recorded manually and therefore the typical energy usage spectrum is unclear including the energy baseline. The last section of the report presents the reference-list followed by Appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature about energy generation, including relevant debates from academic literature and other non-academic literature, such as international and national reports. This chapter begins with the debates on climate change, and the global energy transition and how these topics influence the energy sector. It also presented the state of energy and renewable energy in South Africa and then discusses alternative energy generation potential in the country and the possibility of expansion in this industry. The chapter also analyses the energy usage and concludes with the energy consumption profile of the hospital and reviewing why hospitals depend on the central generating system (boiler system). The literature review also suggests a more sustainable solution for the central generation system of hospitals, such as the use of natural gas in the local generating system and backup.

2.2 Urbanisation and Sustainable Development

Currently, the world is undergoing the second urbanisation wave from 1950 – 2030, with an estimated 609 million people living in urban areas in Africa (Swilling and Anecke, 2012). According to Turok and Borel-Saladin (2014), urbanisation has been predicted to have the potential to transform the developing world by changing the socioeconomic conditions of cities. However, this depends on how urbanisation has been planned for and where it occurs (Turok and Borel-Saladin, 2014). The increasing urbanisation of cities worldwide has intensified the demand for local authorities to ensure the provision of essential services, including energy. (ibid). Since 2015, many countries have adopted the 2030 Agenda for Sustainable Development, including the 17 goals of sustainable development (World Cities Report, 2020). The role of cities has been embroiled in sustainable development as the local government is one of the key drivers to a sustainable future. SDG 11 states that "Cities and human settlements inclusive, safe, resilient and sustainable," and SDG 7 states "affordable, reliable, sustainable and modern energy for all," are critical goals developed to forge a path in cities to reduce the use of fossil fuels and to mitigate the global climate change implications which are a result of greenhouse gases (GHG) (World Cities report, 2020).

Cities in Gauteng province have also experienced very high but uneven urbanisation. Increases have occurred faster in two of the metropolitan municipalities: the City of Johannesburg (COJ) and the City of Tshwane (COT), followed by Ekurhuleni Municipality (Turok and Borel-Saladin, 2014). This uneven pattern presents different challenges and opportunities in the cities and the province (ibid). There is a high demand for public services in large municipalities and a demand for jobs and livelihoods from the citizens (ibid). The rapid increase in the population requires basic amenities, including water, energy, and sanitation. This also puts pressure on natural water courses, energy supply, and air quality, threatens resource scarcity, and increases the country's vulnerability to climate change impacts (World Bank, 2019).

2.3 Climate Change

The impacts of climate change necessitate a just transition from using fossil fuels to using renewable energy (REN21, 2020). Hernandez, Jordaan, and Kaldunski (2020) argue that the renewable energy sector has the highest potential to decarbonise the fossil fuel power generation sector; however, many factors must come into play before decarbonisation is successful (Hernandez et al., 2020). There are notable synergies between climate change mitigation and sustainable development (Hernandez et al., 2020). The linkage between the latter works mutually as sustainable development is the leading cause for the mitigation of climate change, while the impacts of unmitigated climate change impend sustainable development (Hernandez et al., 2020). The renewable energy sector also indicates exponential growth in the renewable energy market, which contributes to the economic development of a country (REN 21, 2020; Hernandez et al., 2020). These synergies between climate change and sustainable development create a path to the implementation of SDG 7 "affordable, reliable, sustainable and modern energy for all" (Hernandez et al., 2020).

Sustainable development actions are sometimes common to climate change mitigation, but the difference is that the motive for one is local development, while the other is emission reduction (Hernandez et al., 2020). According to the Brundtland report, sustainable development can be defined as "to meet the needs of the present without compromising the ability of future generations to meet their own needs "(World Commission on Environment and Development

WCED, 1987). This definition emphasizes the importance of balancing economic growth, social progress, and environmental to ensure the well-being of all people and the planet. Climate change mitigation intends to reduce the threat to the integrity of ecosystems, biodiversity, and natural resources essential for sustaining life on Earth (Sintayehu,2018). Sustainable development requires safeguarding environmental resources and reducing greenhouse gas emissions to mitigate the impacts of climate change on ecosystems, water resources, and air quality (Sintayehu,2018).

South Africa depicts a typical developing country's emissions profile, with high emissions per Capita GDP, indicating that development is still a priority over climate change mitigation (Carbon Tracker, 2020). The United Nations Framework Convention on Climate Change (UNFCC) has, over time, sparked debate over the emission reduction targets if these do not impose development limitations on developing countries compared to developed countries (Nerini et al., 2019). According to Tucker Davey (2016), developing countries need fossil fuels since they cannot afford to transition to renewable energy without the required investment; their economies must grow, and only then can their renewable energy targets be met (Davey,2016).

2.4 The Global Energy Transition

The global energy transition, defined as the 'complete decarbonisation of the world energy system by 2050', is a growing debated phenomenon in global policy (Hafner and Simone, 2020). Alstone, Gershenson, and Kammenet (2015) argue that the main debate is on improving energy access through a decentralised electricity supply, notably in developing Africa and Asia. There is an opportunity for developing countries to move away from centralised energy systems to off-grid systems, which can cause economic development and growth (Alstone et al., 2015). Even though that is the case, there are already evident challenges for the Global South. The Global Value Chain (GVC) for greener technologies is mostly manufactured and supplied by well-developed countries, and not all of them will be able to benefit, especially the Global South, as private developers view this region as politically unstable and risky for investment.

Goldthau et al. (2020) argue that many developing countries currently have carbon-intensive industrial production and are replicating the case of developed countries which are already highly

industrialised, and the energy infrastructure being built now does not resemble the country's energy mix in the future (Goldthau et al., 2020).

The global transition to renewables offers numerous opportunities, including opportunities in clean energy like green hydrogen (Hosseini and Wahid, 2016). However, the shift to renewable energy also presents challenges. Much of the debate around the energy transition has focused on the energy aspect of achieving a secure and reliable energy supply while reducing carbon emissions and ensuring affordability for consumers (Dodd et al., 2020). Although the issue of secure energy is important, the failure to consider key aspects such as equal energy distribution to people can negatively affect the Just transition. Equal energy access is crucial for addressing energy poverty and promoting social inclusion (Dodd et al., 2020). Energy transition efforts should prioritize providing affordable and reliable energy services to low-income communities, including rural areas, informal settlements, and marginalized populations, to improve livelihoods, health outcomes, and overall well-being (Dodd et al., 2020).

2.5 The state of Energy in South Africa.

The generation and supply of sustainable and reliable energy is a critical challenge in the future of sustainable development in the country (State of Energy Report, 2020). Energy is considered a critical contributor to any developing country's economic and social development (State of Energy report, 2020). The Department of Mineral Resources and Energy (DMRE) developed the White paper on Renewable Energy in 2003, which is one of the government's efforts at the National Level to lay a foundation for the promotion of renewable energy such as Solar, Biomass, Hydro, and Wind Power (DMRE, 2003). According to the State of Energy report (2020), South African cities have been making efforts to energy transition; however, the energy sector is facing one of the periods of change where old certainties no longer hold, which include the selling of energy, which is diminishing, energy poverty is high and an unreliable supply of energy from Eskom (State of Energy, 2020). Climate Change is mostly an energy-related phenomenon in South Africa and can be highly mitigated through the transition from dependence on coal to the use of a diversified renewable energy mix, however, many challenges hinder the acceleration of the renewable energy sector.

Coal has remained the predominant source of energy in South Africa, contributing over 80% of the total power generation between 2022 and 2023 (Energy Chamber, 2023). This heavy reliance on coal reflects the country's historical dependency on its abundant coal reserves to ensure energy security and meet industrial demands. Despite global trends toward decarbonisation, coal is expected to retain its significance in the short to medium term, with its share projected to account for 75% of the total power generation by 2025 and approximately 65% by 2030 (Energy Chamber, 2023). Conversely, renewable energy sources such as solar photovoltaic (PV), solar thermal, onshore wind, hydro, and bioenergy have played a limited role, comprising only 10% of South Africa's energy mix in 2022 (Energy Chamber, 2023). However, a gradual transition is anticipated, aligning with the country's commitment to a just energy transition. By 2025, renewables are projected to contribute 13%–17% of total power generation, increasing to 25% by 2030 (Energy Chamber, 2023).

This shift signifies South Africa's strategic efforts to diversify its energy portfolio and address critical issues like load shedding while adhering to its green energy aspirations. To support this transition, the overall power generation capacity is expected to grow from 255–260 terawatt-hours (TWh) in 2022–2023 to approximately 270 TWh by 2025, and exceeding 300 TWh by 2030 (Energy Chamber, 2023). These developments underscore the balancing act required to transition from coal-dependent energy generation to a more sustainable and resilient energy framework, ensuring both energy security and environmental sustainability.

2.6 Overview of the renewable energy sector

While coal has successfully helped generate electricity, it has also placed South Africa among the world's top 10 greenhouse gas emitters (Akinbami, Oke, and Bodunrin, 2021). The government, in partnership with the private sector, has made efforts towards CO_2 mitigation and the development of renewable energy sources. The country understands the need for renewable energy sources to complement as an alternative to its fossil fuel-based energy sector (Akinbami, Oke, and Bodunrin, 2021). The energy mix in South Africa has been diversified, even though fossil fuels are still leading (Akinbami et al., 2021). Figure 2 below shows the percentage of the energy

generation mix in South Africa, with renewable energy totalling up to 5.5%, while fossil fuels make up 8.8% (Akinbami et al., 2021). To support the renewable energy sector, the government released a White Paper in 2003 detailing how the country would generate 10 Terawatt (TWh) of electricity from renewable energy sources (DMRE,2003). In 2011, the government released another policy document, the Integrated Resource Plan (IRP), which had targets of generating approximately 17,000 MW of renewable energy by 2030. Immediately thereafter, the Renewable Energy Independent Power Producer's Programme (REIPPP) was announced to attract the private sector to invest in renewable energy programs. This program accelerated renewable energy generation with over 92 renewable energy projects, which consist of onshore wind, Solar PV, landfill gas, biomass, and small hydro projects (Akinbami et al., 2021).

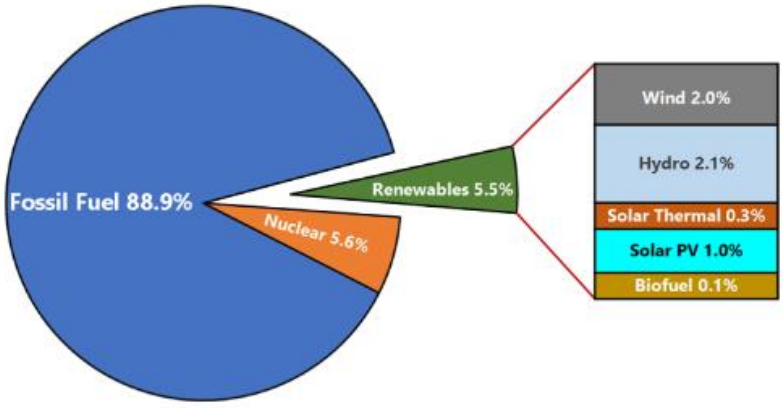


Figure 2: Energy Mix in South Africa, Source: (Akinbami et al., 2021)

Below is a summary of the different renewable energy types to be discussed, as referred to in the white paper for renewable energy.

2.6.1 Biomass/biofuel

Biomass energy is a renewable source of energy produced from organic waste. This type of energy predominates in rural areas and poor households because of its nature. Biomass is usually used for Cooking and heating through the burning of wood, tree branches, and animal waste (Akinbami et al, 2021).

2.6.2 Wind

The wind has been a renewable energy source usually used in the Western and Eastern Cape for domestic and agricultural purposes. Approximately 7 Terawatts/year can be generated from the wind (Akinbami et al, 2021). This source of renewable energy is not as commercial due to the restrictions in location based on wind and wind speed.

2.6.3 Solar energy

South Africa has a vast solar potential across the different provinces, with a vast concentration of Direct Normal Irradiation (DNI), which is the highest in the Northern Cape province and KwaZulu Natal (Akinbami et al., 2021). Solar energy is directly harvested through photovoltaics to produce electricity or solar power by using lenses or mirrors to concentrate and produce steam, which powers a steam turbine. Solar Water heating is also highly used in hospitals and households to reduce electricity bills and dependence on coal (Akinbami et al., 2021). There has been an unprecedented rooftop solar boom as of 2012, with approximately 2700 MW of installed PV solar power capacity in its grid (Ferris, 2023). Solar technology has been adopted in health care institutions and can be economically beneficial for heating water and buildings or augmenting conventional steam or hot water systems (Ferris, 2023). Netcare, a healthcare group in South Africa, has installed solar panels at 72 of its facilities to generate electricity and reduce its environmental impact. Netcare has also implemented other sustainability initiatives, including optimizing water heating systems, using smart metering to monitor energy use, installing heat pumps and heat reclaiming systems, Using LED lights and motion sensors, and Implementing water recycling and saving mechanisms (Daily Maverick, 22 May 2023).

2.6.3.1 Solar Photovoltaic (PV)

Solar PV systems have been instrumental in South Africa's renewable energy strategy, primarily due to their scalability and declining installation costs. PV systems directly convert sunlight into electricity, making them highly adaptable for a range of applications, from residential to industrial facilities (Tiwari et.al 2023). Rooftop solar PV installations are particularly relevant in urban settings, including schools, office accommodations, and hospitals, as they provide a reliable and decentralised energy source that can reduce reliance on coal-generated electricity.

2.6.3.2 Solar Thermal

Solar thermal technology offers another promising avenue for South Africa's energy diversification. Unlike solar PV systems, solar thermal solutions capture and store heat energy from the sun, which can then be used for various applications such as water heating, space heating, and even cooling (Tiwari et.al 2023). This makes solar thermal systems especially suitable for energy-intensive facilities like hospitals, where hot water and thermal energy demands are consistently high. These systems can reduce operating costs and carbon emissions while ensuring uninterrupted energy supply for critical functions (Tiwari et.al 2023).

The integration of solar PV and solar thermal technologies into hybrid systems, known as photovoltaic thermal (PVT) panels, combines the advantages of both approaches. These panels simultaneously generate electricity and heat, maximizing energy yield from a single installation. For instance, solutions such as those developed by companies that specifically target industries like healthcare, where energy efficiency and reliability are paramount. PVT systems offer hospitals a sustainable energy source that meets both their electrical and thermal energy requirements, making them a game-changer in the renewable energy sector. Hospitals present unique energy challenges due to their 24/7 operations and high demand for both electricity and thermal energy (Tiwari et.al 2023). Solar thermal and PVT systems provide tailored solutions that address these needs.

By prioritising the deployment of Solar PV, Solar Thermal, and PVT systems, South Africa can not only accelerate its renewable energy transition but also address the specific energy demands of key facilities like hospitals, schools, and office accommodations. This strategy represents a significant step towards achieving a balanced and sustainable energy framework.

2.6.4 Biogas energy generation

South Africa has biogas potential from biogas plants that operate from sludge and organic waste extracted from landfill sites. Biogas can potentially offset about 2,500 MW of Eskom electricity (Akinbami et al., 2021). The biogas from anaerobic digestion can be a solution to the increasing energy crisis. It can be used for electricity generation, cooking, and transporting fuel. The key advantages of biogas include a reduction in pollution and energy shortage (Akinbami et al, 2021).

Despite the potential for biogas in South Africa, there are several barriers to entry for interested investors. These include the high initial capital costs of building biogas plants (compared to other renewable energy sources, such as wind and solar), the lack of government incentives and subsidies, and the limited availability of suitable feedstocks in certain regions (Greencape,2022).

2.7 Natural gas

The use of natural gas in South Africa is very high even in hospitals, with reserves available from neighbouring countries such as Mozambique and Namibia and the discovery of offshore natural gas reserves (Altieri and Stone, 2016). The gas industry is currently expanding in South Africa as the country produces approximately 930 000 tons of natural gas, which includes Liquified Petroleum Gas (LPG), Compressed Natural Gas (CNG), and other types of gas, which is a 2.8% contribution to energy and is used as feedstock to produce synthetic fuels (Altieri and Stone, 2016). South Africa is amongst the top eight (8) countries with technically recoverable shale gas reserves in the world (EIA, 2013), which are deposited in the Karoo Basin. The value of this deposit ranges from approximately 3.3 to 10.4% of GDP, which has the potential to employ about 1441 to 700,000 people (Altieri and Stone, 2016).

South Africa has access to a pipeline bringing gas from its production fields in Mozambique to its coal-to-liquids plant at Secunda. It is reported by Rompco (2020) that the capacity of this pipeline is 200 PJ/a (Rompco, 2020). Most of this capacity is in use, with the majority being used internally by Sasol at Secunda and Sasolburg. Some of the gas is delivered to gas-fuelled power plants in Mozambique at Ressano-Garcia, near where the pipeline crosses into South Africa (Rompco, 2020). As such, the harvesting of natural gas in South Africa can make a recognizable change in energy generation and transportation by replacing coal-fired electricity and providing liquefied natural gas (LNG) as a source of fuel for vehicles in the public transport system (ERC Gas Report, 2015).

2.7.1 Cogeneration plants

Combined Heat and Power Systems are called the cogeneration systems. These systems involve the simultaneous usage of heat and power from a single energy or fuel source at the point of use or close to it (Daramola, 2020). An optimal CHP system is designed to meet the heat demand of

the energy user- whether at building, city-wide levels, or industry- because it doesn't cost much to transport surplus electricity than excess heat from a CHP plant. For this reason, Combined Heat Power can be viewed as a primary source of heat, with electricity as a by-product (Daramola, 2020).

Also, CHP can be of many forms and encompass different types of technologies, but will always be required to be an efficient, integrated system that combines electricity generation and a heat recovery system. CHP plants generally convert 75-80% of the fuel source into useful energy using the heat output from the electricity production for heating or industrial applications while most modern plants attain efficiencies of 90% or more (Daramola, 2020). In addition, CHP plants reduce network losses because they are located near the end user (International Energy Agency).

Nowadays, the use of CHP systems in commercial and institutional buildings has increased appreciably (Daramola, 2020). This is because of technical improvements and cost-reductions in smaller scale, often modified, systems that meet the thermal and electrical requirements. Examples of commercial and institutional Combined Heat and Power systems users include offices, hotels, and hospitals, which tend to have significant energy costs as a percentage of total operating costs, as well as balanced and constant electric and thermal loads (Daramola, 2020).

Hospitals are the best candidates for Combined Heat and Power (CHP) systems. This is largely since hospitals are in operations for 365 days a year, 24/7, they demand round the the-clock energy (Daramola, 2020). CHP systems assist hospitals to reduce energy costs, improve environmental performance and augment reliability of energy.

2.8 Hospitals and energy usage

Despite the availability of numerous policy guides, such as the National Energy Efficiency Strategy (2005) and norms and standards on energy efficiency, state-owned Hospitals in South Africa still have no record of explicit actual energy usage across the whole building type. The Department of Health does not have readily available information or statistics for energy consumption for most of its properties. Hospitals are very complex, multi-use buildings with unique energy requirements (Morgenstern et al., 2016). Hospitals rely on a dual energy system to ensure

uninterrupted power supply, with the primary source provided by Eskom's grid. This is supplemented by an on-site central generation system, commonly referred to as the boiler house, which produces thermal heat such as heating and steam production. The operational complexity of hospitals arises from their continuous 24-hour occupancy, catering to critically ill patients and supporting essential medical functions that demand a stable and reliable energy infrastructure (Morgenstern et al., 2015). They operate based on hospital norms and standards, which require monitoring of the thermal environment (indoor air quality), especially in theatres and wards. The hospital's energy demand is also increased by energy consumption from medical equipment, sterilisation, laundries, food preparation, and steam requirements (Morgenstern et al., 2015).

2.9 Steam use in hospitals

Public health facilities produce steam using boiler systems, which require coal or Natural Gas (Compressed or Liquified Natural Gas) as an external source to boil water and transform it into steam used in the hospital (Porto, 2020). Generally, a boiler is a superheated closed vessel designed to burn coal to produce steam at a pressure of 3100 kPa (abs) and a temperature of 400°C to produce thermal energy. The most inefficient issue with generating steam using the boiler is that there is energy loss in the system and emissions from burning coal on site, which poses a health hazard to patients (Porto, 2020). Therefore, steam is not considered the most energy-efficient means of use, even though it has a critical role to play in sterilisation and humidification in hospitals.

Steam permits high energy densities and enables large amounts of energy to be moved around easily. Steam is used for many applications in hospitals, including sterilisation, humidification, heating and providing hot water at the tap or shower (Porto, 2020). Hospitals have a need for large amounts of hot water for sinks, baths, showers, and kitchens. Steam is used as the primary heating medium, and through a heat exchanger provides the hospitals users with the hot water required. Heating in a typical steam hospital is achieved by pumping water around the heating circuits, including radiators etc. This is called low temperature hot water (LTHW). In this type of hospital, the primary medium for heating this circuit is steam (Porto, 2020). The high temperature and penetrating power of steam makes it a suitable method of sterilisation. A central sterile

services department performs sterilisation and other actions on medical devices, equipment and consumables, for subsequent use in the operating theatre of the hospital and also for other aseptic procedures, e.g., catheterization, wound stitching and bandaging (Porto, 2020).

2.9.1 Heating

The hospital's boiler system produces steam that keeps patients and staff warm throughout the day and night. State-owned hospitals require the boiler system to operate for comfortable temperatures in the rooms, wards, and theatres. However, for energy efficiency reasons, this could be done through a renewable energy supply like Solar Power, with backup powering the heating of spaces (Porto, 2020).

2.9.2 Humidification

The HVAC system in hospitals is used for the indoor thermal comfort of building users. The HVAC heats the cold air during winter and cools the warm air during summer (McGain et al.,2016). This process is necessary to provide the correct humidification level according to health building norms and standards. This is done to control any bacteria in the wards and to make sure the rooms are thermally comfortable (Porto, 2020).

2.9.3 Sterilisation of equipment

The sterilisation of materials using steam and pressure is an essential and reliable method of destroying all forms of bacteria in the equipment. The sterilisation of equipment avoids the transfer of bacteria and any transferable diseases (Porto, 2020). The sterilisation process consumes an enormous amount of energy from the boiler supply, especially when several autoclaves are in use at the same time (McGain et al.,2016).

2.9.4 Hot water supply for bathing

The supply of boiling water in hospitals is necessary for the continuous washing of hands and bathing. The patients and staff in the hospital are expected to uphold hygiene to prevent the spreading of any infections to other persons, hence the continuous requirement of washing hands. Patients also require hot water to bathe to prevent bathing with cold water (Porto, 2020).

2.9.5 Gauteng hospitals transition process

The Gauteng Provincial Government developed the Gauteng Integrated Energy Strategy (GIES) to address critical issues related to global climate change, economic instability, and electricity supply challenges within South Africa. The primary aim of the GIES is to provide strategic direction for energy supply and utilisation within the Gauteng Province. It also advocates for exploring various energy solutions to reduce greenhouse gas emissions, promote energy efficiency, and expand renewable energy generation. This strategy seeks to implement an integrated and comprehensive approach to energy planning and management (GIES, 2014)

The GIES has direct implications for the Department of Infrastructure Development (DID), a key provincial entity responsible for developing and maintaining infrastructure in Health facilities. This alignment places significant responsibility on the department to innovate and implement measures aimed at reducing greenhouse gas emissions in accordance with GIES objectives. Consequently, DID is under increased pressure to adopt sustainable practices and integrate energy-efficient and renewable energy solutions into its Health infrastructure projects (Annual performance plan, 2015).

In line with its strategic and policy directives, the Department of Infrastructure Development (DID) initiated a project to convert 27 boilers in health facilities from coal to natural gas. This transition has brought about significant operational changes, primarily due to the distinct differences between coal-fired and natural gas-fired boiler systems. The conversion required a substantial initial capital investment to establish the necessary auxiliary infrastructure to support the operation of the natural gas-fired boilers (Annual Performance Plan, 2015).

These auxiliary systems are essential for integrating the bulk natural gas supply from the supplier’s distribution network to the health facilities, ensuring a continuous, efficient, and reliable energy supply that aligns with the operational needs of these facilities. This infrastructure is critical in optimizing energy delivery, enhancing sustainability, and supporting the department's broader objectives as outlined in its policy framework (Annual Performance Plan, 2015).

2.10 Sustainability of Hospital buildings using the Trias Energetica model.

Human health is a crucial pillar of modern conceptions of sustainability in the Global South (Gurieff et al.,2020). Integrating health considerations into sustainable development strategies can promote inclusive and equitable development and enhance resilience to health-related risks (ibid). Public hospitals are focal points for communities and have an opportunity to lead the energy transition to renewable energy (ibid). The healthcare energy ecosystem, with sustainable technologies, has the potential to transform hospitals into net-zero buildings. The Trias Energetica model is an ideal approach for hospitals to use effectively to improve public sector hospitals' current inefficient status core. Figure 3 shows the 'Trias Energica' model, which has been updated to include a Five (5) step method to achieve sustainability in hospital buildings.

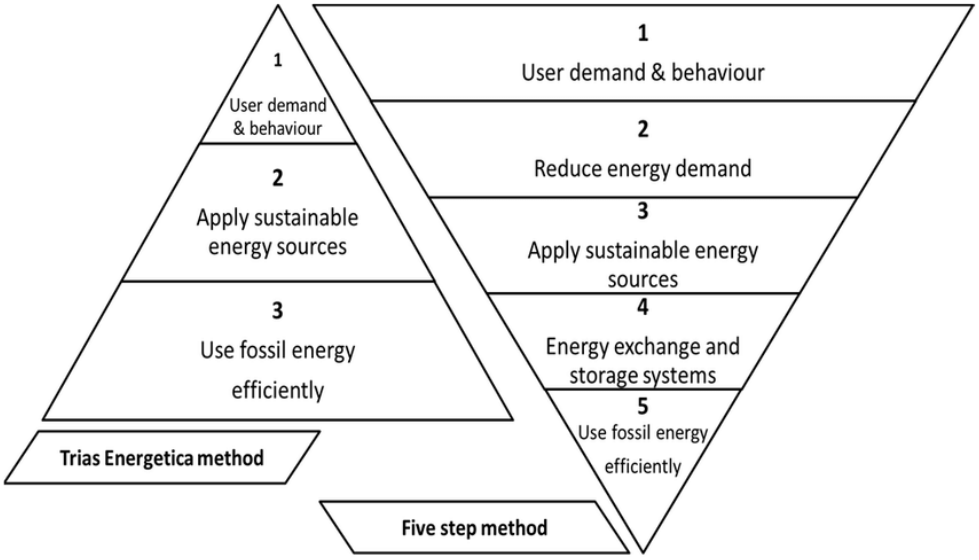


Figure 3: Trias Energetica Five Step Model (Maassen, 2019)

The Trias Energetica has become one of the key strategies for a more sustainable built environment in the Netherlands and has been adopted in the rest of the world. This strategy was introduced by Novem (the Dutch Agency for Energy and the Environment; one of the predecessors of NL Agency) back in 1996 (Maassen,2019). The three elements of the Trias Energetica are:

1) User demand and behaviour;

2) Use renewable sources of energy;

3) If fossil fuels are still needed, use them as efficiently and cleanly as possible.

The model was then modified through a 5-step method to include the following steps:

4) Energy exchange and storage systems; and
5) Reduce the demand for energy.

This model is aligned with the Net Zero Buildings (NZEB), as the NEZB guidelines are part of energy-efficient strategies (Attia, 2018). As buildings represent 30-40% of their energy use, reducing their energy demand is key to achieving NZEB (Attia, 2018). NZEB can be defined as ultra-low buildings that are able to meet their energy needs annually through renewable energy produced onsite or nearby (Attia, 2018)

Although this model has been very useful, there are aspects it does not address, such as the quality of energy needed and the scale at which it should be provided. For example, the required quality of energy is low-temperature heating systems which is able to outperform traditional high-temperature systems and therefore lead to a more sustainable solution (Maassen, 2019). These aspects are relevant if we want to find optimal solutions for the built environment (Maassen,2019).

2.11 Supply of alternative energy and renewable energy to the hospital

Public hospitals do not operate as businesses, as they form part of social infrastructure. However, they need valid energy business cases to decrease their energy costs. Hospitals consume more energy than any other normal building because they operate 24 hours daily (Sithole, 2016). As argued, for hospitals to become sustainable, they must introduce renewable energy as a source of energy generation, which will completely replace the central energy-generating system (Sithole, 2016). Public Hospitals have yet to fully consider solar panels, hydropower, wind turbines, natural gas, etc., as alternative energy sources because of many barriers. The scepticism surrounding new renewable technologies and the frequency of power outages from traditional utilities creates uncertainty regarding the transition to renewable energy (Mac-Kinnon, 2018). Renewable energy sources depend on natural conditions for energy generation and generation

time. However, to reduce the effects of their irregular generation time, the concept of energy storage and supply back to the grid needs to be more noticed (Weimann and Patel, 2017).

2.12 Steam boilers

Steam boilers play a critical role in various industries and facilities, including power generation plants, breweries, sterilisation units, and in processes like trace heating of fuel or oil pipes to reduce flow viscosity (Stauss, 2017). According to Sarkar (2015), boilers are integral to daily life and are pivotal in generating steam for electricity utilities. Hospitals, specifically, rely on boilers to produce steam essential for numerous operational functions (Ganapathy, 2003).

Kohan and Spring (1991) describe a boiler as a closed pressure vessel that heats fluid for external use by utilizing energy from fuel combustion (solid, liquid, or gaseous) or alternative sources like electricity or nuclear power. Woodruff and Lammers (1977) further elaborate that fuel, containing chemical energy, is converted into heat within the boiler. The boiler's design ensures the efficient transfer of this heat to water. During the combustion process, the boiler must maximize heat absorption, employing mechanisms such as radiation, conduction, and convection. Steam boilers are broadly categorized into two main types based on design and functionality. In this configuration, hot gases from combustion pass through tubes surrounded by water. The heat transfer from the gases to the water generates steam. These boilers are typically used for low-pressure applications and are favoured for their compact size and simplicity.

Water-Tube Boilers are feature water-filled tubes that are exposed to the heat from combustion gases. These boilers are suitable for high-pressure and large-scale applications, making them ideal for power plants and industrial operations due to their efficiency and capability to generate steam at higher pressures and temperatures (Stauss, 2017).

High pressure steam boilers generate steam vapor at a pressure of more than 1.03 bar, while a low-pressure steam boiler operates below 1.03 bar and is classified as a miniature boiler (Ganapathy, 2003).

The type of steam boiler required for use in a particular application depends on the pressure, temperature, and amount of steam required. Low-pressure steam boilers are used primarily to

heat buildings such as schools, apartments, and warehouses and to heat domestic water. Alternatively, high-pressure steam boilers generate electricity and facilitate industry processing operations. These boilers are well suited for a hospital setup. According to Hasnain et al. (2020), the selection of industrial boilers requires a sound decision as the decision always has a direct impact on issues such as steam temperature, pressure, and demand for steam; hence the type of boilers to be utilized must be specific.



Figure 4: Image of a gas-fired boiler, source (123RF)



Figure 5: Image of a coal boiler (123 RF).

According to Malek (2007), Steam boilers are classified according to the fuels used: gas-fired boilers, oil-fired, coal-fired, and electric boilers. These fuels act as the heat source in boilers for steam generation or hot water production for space heating and hot water use. Before 2015, all 37 hospitals in Gauteng relied on coal boilers for their steam generation needs. However, following the implementation of coal-to-gas conversion projects, most of these hospitals transitioned to using gas boilers. This shift aimed to reduce the environmental impact associated with coal use, aligning with broader efforts to decarbonize energy sources and improve air quality. However, most hospitals halted the use of Gas due to the cost of gas and defaulted back to using coal which is deemed cheaper (Annual operations plan, 2021).

2.12.1 Steam Boilers at Helen Joseph Hospital

Hele Joseph Hospital has two steam boilers (1 coal, 1 natural gas) which are located on site at the boiler house. The coal boiler is a steam boiler which is a closed vessel, made of steel, in which water is heated through combustion of fuel coal and ultimately to generate steam. The steam produced is supplied at low pressure for hospital usage etc. and for producing hot water which can be used for heating installations at much low pressure.

When water is boiled into steam its volume increases, producing a grander force like explosive that will run produce steam (Malek, 2007). This indicates that a boiler is extremely risky equipment that must be treated with supreme care. Below is a pictural image of a coal boiler like that at Helen Joseph Hospital

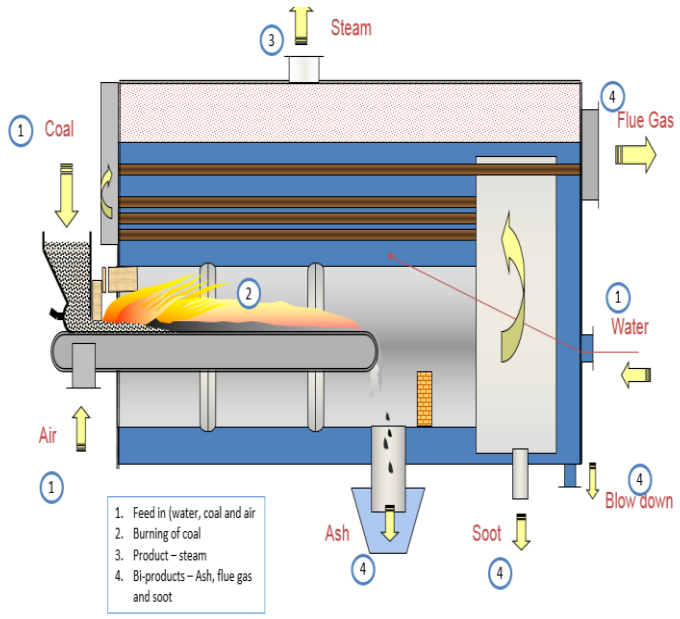


Figure 6: Sectional view of a coal fired boiler ((source: Krarti, 2018)

The typical coal boiler depicted above works whereby coal is crushed into fine particles to enhance combustion efficiency. The prepared coal is hand shoveled or fed into the boiler furnace using systems like conveyors or augers. The coal gets to the combustion Chamber where there is a furnace, the coal is burned at high temperatures, generating heat. Air fans supply the necessary air (oxygen) to support combustion. Air may be preheated for better efficiency. The heat generated in the furnace is transferred to water contained in tubes lining the boiler walls. These

tubes are strategically placed in the path of hot gases to maximize heat absorption. The water absorbs the heat, gradually converting into steam. As the water temperature increases and reaches its boiling point, it changes into steam. The saturated steam collects in a steam drum, separating from water droplets. The combustion gases (flue gases) exit through the chimney after passing through a heat exchanger to recover residual heat. Ash, the non-combustible residue from burned coal, is collected, and disposed of. This process illustrates the critical components of a coal-fired boiler system, highlighting its reliance on efficient combustion, heat transfer, and steam generation.

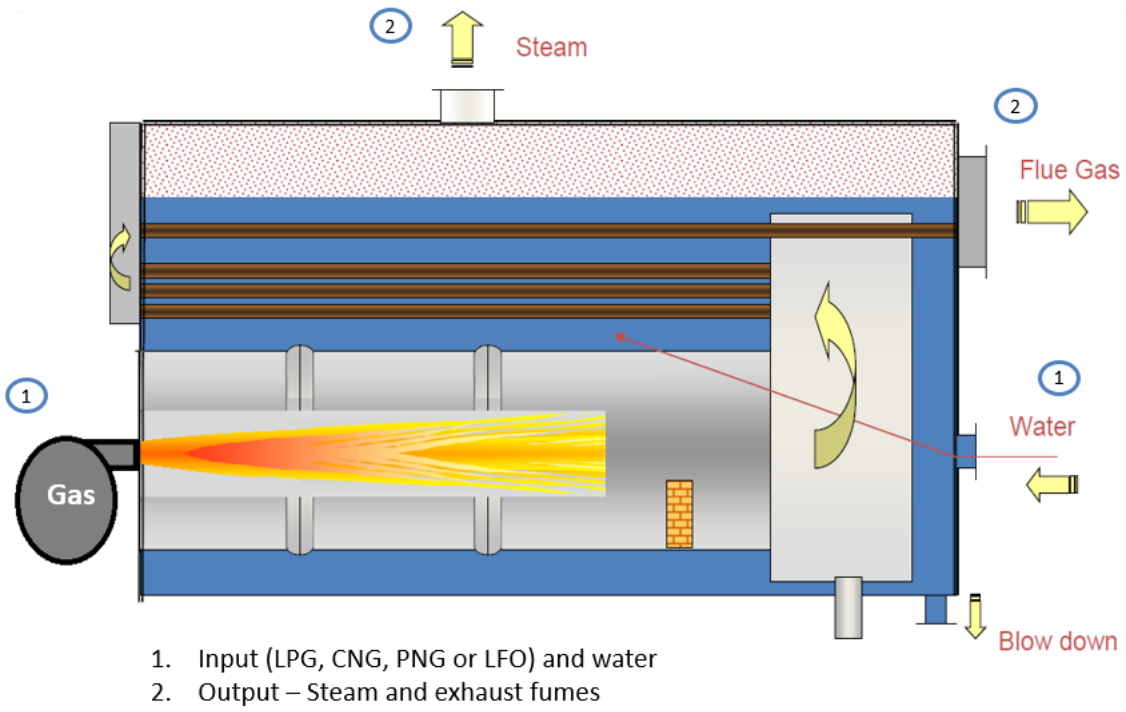


Figure 7: Sectional view of a natural gas fired boiler (source: Krarti, 2018)

The natural gas boiler at Helen Joseph Hospital operates by burning natural gas to generate heat, which is then used to produce hot water or steam. The natural gas is delivered to the boiler via a pipeline system and controlled using valves to regulate the flow. An electronic ignition or pilot light ignites the natural gas. The natural gas is mixed with air in the burner and ignited, producing a flame. The flame burns in the combustion chamber, releasing heat. The heat generated by the burning gas is transferred to water inside the heat exchanger, a system of metal tubes or coils.

As the water absorbs heat, its temperature increases, converting it into hot water or steam depending on the boiler type. The water turns into steam, which is collected and directed to its application. The by-products of combustion, such as carbon dioxide and water vapor, are safely vented through a flu or chimney.

2.13 Best practice in global case studies

Vourdoubas, 2022 reviewed the use of Combined Heat and Power (CHP) systems in hospitals across the United Kingdom (UK), noting that CHP systems are widely used in England and can provide reliable heat and power. These systems are especially beneficial in healthcare settings, where energy demands are high, and uninterrupted power is critical Vourdoubas (2022). The study highlighted that CHP systems can offer consistent energy supply, reducing the reliance on external grids and improving energy efficiency. The author further explains the role of CHP systems in enhancing hospital resilience. According to Vourdoubas (2022), hospitals equipped with CHP systems are able to provide reliable off-grid power during major disruptions, such as grid failures or emergencies. This capability increases a hospital's resilience, ensuring that essential services continue even during power outages (Vourdoubas, 2022).

The advantages of utilizing Combined Heat and Power (CHP) systems in hospitals have been extensively analysed in Singapore (Changi General Hospital), United Kingdom (University Hospital of Wales, Cardiff), Australia (Royal Melbourne Hospital) and Germany (Berlin Charité Hospital. These benefits encompass enhanced energy reliability, increased hospital resilience during disasters, and reduced energy costs. Additionally, CHP systems meet hospitals' demands for electricity, hot water, and space heating and cooling. An evaluation of both current and potential CHP capacity in U.S. hospitals reveals that the existing capacity is 772 MW, with the future potential capacity projected to reach 7,312 MW. These systems are recognized for their reliability, which not only improves hospital resilience but also eliminates the need for costly backup power systems (Vourdoubas, 2022).

Gas-based systems, including gas boilers and CHP systems, are well-established technologies with proven performance and reliability in various sectors, including healthcare. While renewable energy technologies are advancing rapidly, they may still face challenges such as energy storage

or intermittent supply, especially in the context of a hospital's critical energy needs. Hence this research focusses on coal to Gas conversions.

2.14 Conclusion

Analysing and reviewing South Africa's commitment to reducing greenhouse gas emissions is crucial for understanding the challenges in the energy sector before implementing systems that can promote renewable energy in the country. Eskom will play a key role in driving the decarbonisation process for it to be truly effective. There is a significant opportunity for South Africa to transition from centralised energy systems to off-grid solutions, which could enhance energy efficiency, particularly in healthcare facilities (Alstone et al., 2015). Hospitals, as major consumers of steam for various functions, could benefit from such a transition. To move away from centralised power generation and adopt a more sustainable approach, it is important to assess why state-owned facilities have not yet implemented sustainable energy systems, despite the challenges posed by Eskom's unreliable power supply. Considering this, it is necessary to consider both the advantages and disadvantages of shifting to renewable energy systems in these facilities. alternatives should also be balanced, especially considering the impact of the process on patients and the cost of energy.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the researcher highlights the research design, the sampling techniques, and the procedures used to obtain the data. An outline of the data collection methods from the literature is discussed, as well as the best method that suits the data collection at the chosen hospital. This includes data collection and analysis tools as well as related ethical considerations. The chapter concludes with an overview of the selected hospital, which is the case study of the research. The techniques to be used in this research report are explained. The pros and cons of using each of the preferred methods and the research limitations will be explored. Lastly, the ethical considerations of the study are addressed.

3.2 Case Study Overview of Helen Joseph Hospital

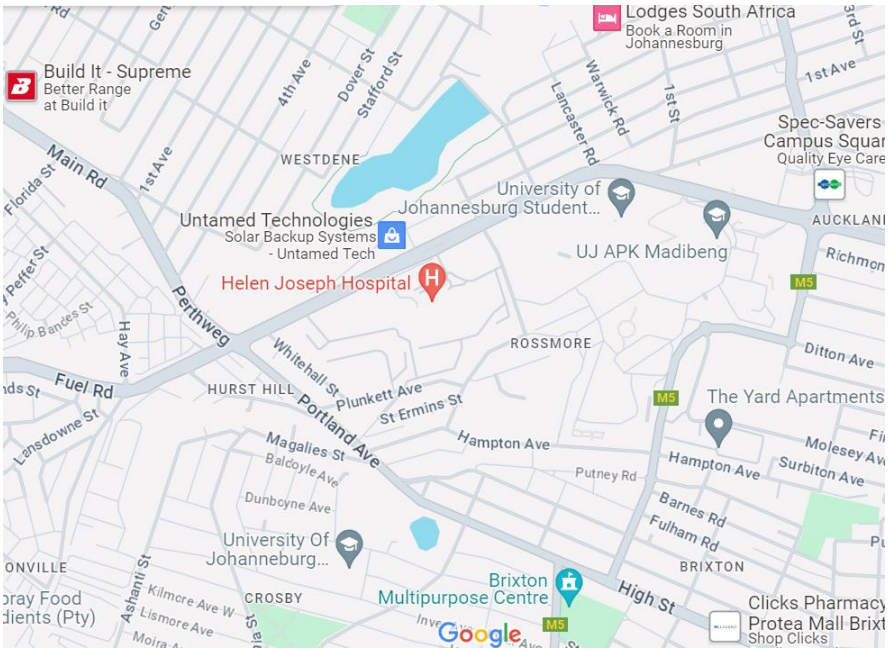


Figure 8: Location of Helen Joseph Hospital in Johannesburg Westdene area, source (Google Maps)

Helen Joseph Hospital is a tertiary level 3 Hospital based in Westdene area, Johannesburg. The hospital comprises of 23 wards, 13 clinics and 11 theatres. The hospital was built in 1962.

The notable centres of excellence and services that the facility provides include and are not limited to Orthopaedics, Renal Clinic, Medicine and sub-specialties, General Surgery and sub-specialties, Allied health, Breast clinic, Stoma and wound management clinic, Pain clinic, Lung laboratory, Thembalethu HIV clinic, and Focal point (Gauteng Government). The hospital, in the past 3 to 5 years, has been facing challenges of water shortages, High electricity costs owing approximately R44 Million to City Power, and overcrowding in the hospital.

3.3 Research Methodology

The phenomenon to be researched is the transition from coal to gas for the central generation system of hospitals. Bryman and Bell (2011) state that research design is essentially a framework for the collection and analysis of data to derive the findings on the research question. Based on the insights from the literature review in Chapter 2 and the research question raised in Chapter 1, the study applied a qualitative approach based on the case study of a purposely selected hospital. Baxter and Jack (2008) suggest that a case study approach provides the exploration of an issue through a variety of lenses and considers different features of the phenomenon of the study. However, the study also entails numerical information on energy usage (electricity bills), cost of coal vs gas. The study will use primary data from key informants and secondary data sources to lay a background and interpretation of the findings. The participants were selected based on specific criteria relevant to the research question rather than through random sampling techniques. This approach enabled the researcher to gather in-depth insights about individuals' perceptions, experiences, and interpretations of research (Neuman, 2014)

3.4 Data Collection Methods

Qualitative data collection methods such as interviews, observations, and document analysis) tend to rely on random sampling since the results need to be generalized to the broader population (Du Plooy-Cilliers et al., 2014). For this research, interviews (in-person and online) were the essential methods of data collection. The method of sampling used was purposeful sampling. Purposeful sampling is widely used in qualitative research to identify and select information-rich cases related to the phenomenon of interest (Palinkas, 2015).

3.5 In-depth Interviews

In-depth interviews were the primary data collection tool. The interviewing was based on conversation, emphasizing researchers asking questions, listening, and respondents answering (Rubin and Rubin, 1995). Boyce & Neale (2006, p7) argue that when choosing interviewees, one should consider a sample that best represents the diverse stakeholders and opinions of those stakeholders. The researcher used purposeful sampling to select diverse stakeholders directly involved in boiler operating and managing steam generation in the Hospital. The interviews identified relevant officials, including hospital boiler management, boiler operators, chief engineers, facility managers, finance staff, and artisans working in the boiler house. The interviews were semi-structured, which allowed a dialogue between the researcher and the participant. They were guided by a flexible interview protocol and supplemented by follow-up questions, probes, and comments. Approximately 20 Interviews were scheduled, and appointments were booked for discussion. However, successfully, 15 interviews were conducted and recorded.

3.6 Observation

The researcher visited the hospital on two separate occasions to observe how the boiler system operates and how the 36-month maintenance schedule is managed. This was done so that the researcher could better understand how the system effectively functions. This approach aligns with qualitative research methodology, specifically with participant observation. By visiting the hospital on two separate occasions to observe the operation of the boiler system and the management of the 36-month maintenance schedule, the researcher gained first-hand insight into the system's functioning in its natural context.

3.7 Data analysis techniques

Given that the topic being researched involves understanding the operation of the boiler system and the management of maintenance schedules in a hospital setting, qualitative data analysis methods were selected as the most suitable method. The method used for analysing the data is primarily qualitative. The qualitative analysis methods offered flexibility and adaptability to the research context, allowing the researchers to tailor their approach to the specific needs and characteristics of the study. Basic numerical data sets were also analysed, including electricity

bills and the cost of fuels, which were analysed, and patterns identified meaningful conclusions drawn. The analysis included the grouping of key themes derived from the interviews: boiler systems, energy consumption, environmental impacts, energy transition cost of energy, and Green Technology policies.

3.8 Expected findings.

It Is expected from the findings that there are possible methods to reduce steam consumption, switch from using coal to using an alternative energy supply, and or use renewable energy in the hospital facilities. All public hospitals in Gauteng have their central generation plant operated on coal or gas to produce steam. The coal system releases large amounts of greenhouse gas (GHG) emissions that contribute negatively to the environment, and this energy generation happens on hospital premises. However, legislative, political, and financial constraints hinder the success of alternative fuel types such as natural gas.

3.9 Ethical considerations

Neuman (2014) indicates that researchers have an obligation to the participants to obtain informed consent from the participants, ensure privacy, and should practice research ethics throughout. Before beginning the research process, the researcher followed and adhered to the University of the Witwatersrand's ethical principles and guidelines. The researcher received permission from the Department of Infrastructure Development (DID) as the custodian of Health Infrastructure in Gauteng to access the Helen Joseph Hospital boiler facility for research purposes. The participants were given an introductory letter from the University, and consent was sought from the interviewed participants. All data collected was used for research purposes only, and the researcher will protect the participant's confidentiality, anonymity, and pseudonyms while collecting, analysing, and reporting data.

3.10 Data Collection and analysis tool

Data collection and analysis tools are the methods that were used to collect the data that emanate from the research question and the related sub-questions that the research aims to answer. Many governments and institutions are targeting an immediate reduction in greenhouse gas emissions. Transitioning from coal to natural gas can provide a practical and relatively quick

pathway compared to adopting newer and less established renewable energy infrastructures. Hence the research focusses on transition from coal to gas.

The table below summarises the data collection tools and analysis applied in the research.

Table 1: Summary of data collection tools and data analysis applied.

Research Question and Sub-Questions	**Required data**	**Data collection tools**	**Data Analysis Process**
• How can public health facilities transition from coal-fired to natural gas-fired central generating systems to improve energy efficiency, reduce environmental impact, and ensure sustainable and reliable energy generation?"	**Primary Data** • Hospitals transition plan • Energy Demand Data: current energy consumption. • Existing Equipment (coal boiler) • Historical data on operational efficiency, downtime, and maintenance costs of current systems. **Secondary Data**	• Collect data through semi-structured interviews. • Collect data from the engineers and energy experts in the hospital. • Use of existing case studies and literature.	• An analysis of the data will be done through Charts, Graphs, and Tables • Analyse data and group it into themes in chapter 4 of the research study. • Data will be analysed and grouped into

	• Site visits, technical inspections, and interviews with facility managers and engineers		themes comparing coal and gas
• What are the operational inefficiencies, environmental impacts, and energy outputs of existing coal-fired central generating systems in public health facilities?	• Comparison of the coal vs Natural Gas operations and emissions when generating energy. • Health benefits compared to health degradation.	• Use of existing literature	• Data will be analysed and grouped into themes. • Compare emission data through an analysis.
• How can transitioning to natural gas-fired systems contribute to the long-term sustainability of public health facilities?	• Barriers can be identified through the in-depth interview responses. • Hospital's climate change action plans or targets	• In-depth interviews sessions • Collect data on the energy-generating methods, • Review the hospital's climate change policy or action plans.	• Conduct a comparative analysis.

• What technical and institutional barriers exist in the transition to natural gas-fired systems at Helen Joseph Hospital and how can these barriers be addressed to encourage adoption?	• Technical barriers, institutional barriers, and potential solutions.	• This information was collected through semi-structured Interviews with the Boiler management staff, including Chief Engineers, Facility managers, Boiler operators, and building inspectors of Helen Joseph Hospital.	• Data will be analysed and grouped into themes.

CHAPTER 4 UNDERSTANDING FACTORS CONTRIBUTING TO THE LOW ADOPTION OF ALTERNATIVE ENERGY (NATURAL GAS)

4.1 Introduction

This chapter presents data and aligns to the research aim, which is to analyse the transition from coal-fired to natural gas-fired central energy generation systems in public health facilities, focusing on Helen Joseph Hospital, with particular emphasis on environmental, economic, and operational issues. This involves evaluating the environmental impact of switching fuels, such as the reduction of greenhouse gas emissions, the economic feasibility of retrofitting or replacing systems, and the operational implications, including infrastructure changes and system reliability. The aim reflects the broader goal of identifying sustainable energy solutions in line with legislative, environmental, and healthcare delivery objectives. The focus is on addressing the main research question, " How can public health facilities transition from coal-fired to natural gas-fired central generating systems to improve energy efficiency, reduce environmental impact, and ensure sustainable and reliable energy generation?". This chapter works towards understanding how the boiler systems work and what will be required to transition to natural gas as long-term solution and to other sustainable solutions available in the market.

To clarify the above, the study utilised the Helen Joseph Hospital as a case study to assess how such a facility can use a sustainable solution in the central generating system. The in-depth interviews targeted staff members who operate or work with natural gas-fired boilers and coal-fired boiler energy systems. The interviews also specified the participants' roles in the operations of natural gas-fired boilers and coal-fired boilers, and a 75% response rate was received from the professions targeted.

The chapter presents the primary findings from individual in-depth interviews conducted in person and online through Microsoft Teams and the secondary data, such as the cost of coal vs. gas, electricity usage vs. cost, and the scope 1 emissions from boilers. The data collected has been analysed through themes, and the numeric data has been analysed through graphs, pie charts, and tables, and meaningful conclusions have been drawn.

4.2 Profile of respondents and response rate

In-depth interviewing techniques employed in this research seek details about an individual's beliefs, attitudes, and behaviours, which are critical to answering the research question (Rutledge and Hogg, 2020). The respondents' profiles in the research included boiler operators, engineers, facility managers, maintenance personnel, and hospital Infrastructure managers. The response rate of 75% suggests a high level of participation and willingness among the target population to engage in in-depth interviews.

The Interviews targeted 20 purposefully selected professionals at the Helen Joseph Hospital. Table 2 below shows the participants who were targeted. Only 15 respondents made time to participate in the interviews, either online or in person.

Table 2. Summary of the response rate in percentage.

Interview Requested	Interviews Obtained	Response Rate
20	15	75%

Figure 9 below shows the graphical representation of the response rate and the sample of participants who agreed to participate. This sample is believed to be representative of the broader population or target group.

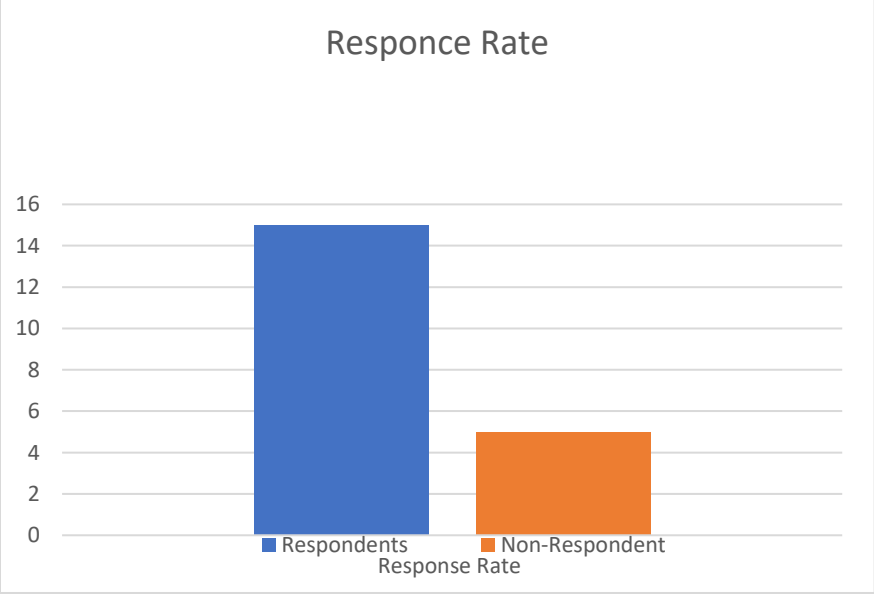


Figure 9: Summary of the response rate in percentages

The comparison between the targeted response and the received response provides insights into the effectiveness of the research methodology and participant engagement. The targeted participants were willing to participate and to provide their insights about the research. Table 3 below shows the summary of the targeted respondents and received responses.

Table 3: Summary of the targeted respondent vs received responses.

Participants	**Targeted responses**	**Received responses**
Boiler Operators	4	3
Engineers	6	4
Facility Management	4	2
Maintenance	4	4
Hospital Infrastructure Management	2	2
Total	**20**	**15**

4.3 Interview data: Emerging themes

The researcher identified six critical themes emerging from the analysis of responses. These themes are categorized as follows: work experience with boilers, operation of coal boilers, cost of energy (coal versus natural gas), cost of electricity, environmental impacts, and decarbonisation strategy.

4.4 Work experience of boiler staff

Boiler operations are a complex and critical process in various industrial and commercial settings (Talwekar, 2023). A deep understanding of the technical aspects involved is crucial to ensure safe, efficient, and reliable performance (Talwekar, 2023). The boiler operation, focusing on critical factors such as fuel combustion, heat transfer, control systems, and maintenance, requires a wide range of skill sets, which include mechanical engineers, electrical engineers, boiler operators, and maintenance personnel. Fuel combustion is the primary energy source in a boiler controlled by the boiler operators. Achieving efficient and controlled combustion requires

precise air-to-fuel ratio management. Combustion control systems monitor oxygen levels, allowing for optimal fuel combustion while minimizing excess air, which can lead to energy losses (Eyre, 2023). Upon the combustion process, the boilers facilitate heat transfer from the combustion process to water or steam. At Helen Joseph Hospital, the boiler system operates as the central energy generation unit for thermal energy which consists of one coal boiler and one natural gas boiler. The boiler primarily producing thermal energy (steam) to support various hospital operations (Eyre, 2023). Steam is used for purposes such as sterilisation of medical equipment, space heating, and water heating. During the site visits it was discovered that the primary boiler is the coal boiler which relies on coal as its primary fuel source. Coal combustion generates heat, which in turn produces steam by heating water in the boiler's pressure vessel. In 2016 one boiler was converted from coal to gas however this boiler is currently not used due to the cost of procuring gas.

For the coal boiler to operate, there must be a delivery and storage of coal onsite, where it is fed into the boiler's combustion chamber. The burning coal generates high temperatures, transferring heat to water circulating through the boiler. The resultant steam is distributed through a network of insulated pipes to the hospital's facilities. This system is energy-intensive and contributes significantly to greenhouse gas emissions and releases coal ashes. There have been efforts to transition this system to natural gas by replacing one of two coal-fired boilers with a natural gas boiler, which burns cleaner and produces fewer pollutants. However, the boiler is not functional, and the main sited challenge is that of the cost of natural gas.

The table below shows the number of years of experience of the respondents based on their profession. The interviewees were asked about their work experience because it influences how individuals perceive and interact with the boiler, including their roles, responsibilities, relationships, and expectations within the workplace and broader society. The information below in Table 4 was extracted from the interviews, and it shows the experience of the staff working on boilers. The highest experienced personnel have approximately 22 years, while the lowest is approximately 6 years.

Table 4: Respondents years of experience

Respondent profession	**Years of Experience**
Boiler Operator 1	22
Boiler Operator 2	15
Boiler Operator 3	8
Chief Engineer	16
Engineer 1	6
Engineer 2	8
Engineer 3	9
Facility Manager 1	10
Facility Manager 2	12
Maintenance 1	14
Maintenance 2	15
Maintenance 3	9
Hospital Management	6
Hospital Management	6

During the interview with the boiler operators, we discussed why it is important to be trained and accredited as a boiler operator and to have sufficient experience. The following information was provided by boiler operators:

It is important for boiler operators to be experienced and familiar with the type of boiler they are working with because boilers are very technical and sensitive plants. If a boiler operator makes a mistake while operating a boiler, the consequences can be very serious. Boilers are pressurized systems that can explode if they are not operated correctly. Even if the boiler does not explode, making a mistake while operating it can result in severe injury or death."

Figure 8 below is a graphical representation of the work experience of the difference staff working with boilers at Helen Joseph Hospital. The information was derived from table 4 above. Most of the respondents have vast experience in the operations of coal fired boiler and natural

gas-fired boiler. From the work experience of the respondents, it can be deduced that most of the interviewed professionals have been working with boiler systems for many years.



Figure 10: Work experience of the respondents

4.5 Operation of a coal boiler

Boilers combine radiation, convection, and conduction to convert heat energy into steam energy (Pearson, 2015). Proper boiler operation depends on controlling many variables, including boiler feedwater quality, water flow and level in the boiler, furnace temperatures and pressures, burner efficiency, and airflow (Pearson, 2015).

The boiler in a hospital is responsible for generating steam, which is used for heating, sterilising medical equipment, and providing hot water for various hospital operations (Li, 2018). Typically coal is commonly used as a fuel for boiler operations in hospitals due to its affordability and availability (Sobota, 2018). In case of fuel shortage, alternative fuels such as diesel or natural gas may be used to operate the boiler, depending on availability and infrastructure.

The first energy conversion takes place in the boiler. Coal is burnt in the boiler furnace to produce heat. Thereafter, the carbon in the coal and Oxygen in the air combine to produce Carbon Dioxide and heat (Sobota, 2018). The second stage is the thermodynamic process, where the heat from

coal combustion boils water in the boiler to produce steam. In modern power plants, boilers produce steam at high pressure and temperature (Sobota, 2018). The steam is then condensed and pumped back into the boiler to repeat the cycle (Li, 2018).

Coal-fired boilers are mainly operated in either subcritical or supercritical conditions, which are the different operational states of boilers, particularly in the context of steam generation (Hossain,2019). From a thermo-physics perspective, two-phase mixtures of water and steam are replaced by a single fact, the supercritical fluid, when the boiler pressure increases above the critical pressure of 22.12 MPa and the corresponding saturation temperature of 374 °C (Zhang, 2013). This means such supercritical conditions require high maintenance; hence, the boiler systems have scheduled daily maintenance and 12-month and 36-month scheduled maintenance to ensure the system's effective operation (Zhang, 2013).

The following information summarizes the interview with boiler operators about their roles and the challenges they face as they operate the boiler.

The role of boiler operators is to manage the daily functioning of the boiler, which includes checking the water level in the boiler and adding water as needed, Inspecting the boiler for any leaks or damages, and testing the pressure relief valve to ensure it is working properly. It also includes cleaning the fire chamber and burners, shoveling coal on the chamber, inspecting the flue pipe for any blockages or damage, and waste management. The challenges faced by boiler operators vary depending here in the hospital; we face common challenges like:

- *Monitoring the boiler's performance and adjusting as necessary to optimize its efficiency because the coal boilers are not digitally controlled but are manually controlled. If we are faced with a situation where the boiler is not producing enough steam, I would check for any blockages in the pipes or valves that may be preventing the proper flow of steam. But if the boiler was digital, the system would indicate; in this case, I manually checked for the challenge.*
- *Keeping accurate records of the boiler's operating parameters and maintenance history is a challenge as all records are recorded on paper and stored in a file; if they are lost, there is no historical record."*

According to Wang 2018, the coal boiler is a high-emission plant with pollutants such as Nitrogen Oxide (NOx), smoke dust, and even Carbon Monoxide (CO_2) that have been produced and emitted (Wang,2018). Among all these pollutants, NOx is the worst one because it can cause severe environmental problems such as (acid rain, depletion of stratospheric ozone, etc.) and health problems (direct damage to many human organs) (Wang,2018). One of the boiler operators indicated that.

The bad thing about coal is that it has the ability to affect the operator's health due to pollution, ash inhalation, dust, and polluted air. This is why boiler operators must always wear protective clothing, including a mandatory mask. I have worked in many plants; boiler operators generally have a respiratory challenge, and they cough a lot. I also handle ash residual from the combustion chamber daily after combustion. This ash must be collected and stored temporarily here on site until the service provider comes to collect it. We spray the ash with water to manage dust.

Helen Joseph Hospital solemnly relies on the coal boiler to generate the steam for the hospital's requirements. The coal boiler is 8000kg/h, which emits 13278.7 t CO_2 e per year. This basically means that the boiler generates 8000 kg (8 tons of steam per hour) of steam per hour under specified conditions (such as temperature and pressure). The fuel consumption (coal): The amount of coal burned per hour depends on the boiler's efficiency and the specific energy (calorific value) of the coal being used. The efficiency of the boiler determines how much of the energy from the coal is converted into steam. Typically, for a coal-fired boiler, the rate of coal consumption can be calculated based on the energy required to produce the steam and the energy content of the coal.

For example, if the coal being used has an energy content of 24 MJ/kg (megajoules per kilogram) and the boiler is 85% efficient, you would calculate the coal consumption needed to produce the energy required to generate the 8000 kg of steam per hour.

The boiler is operated on coal, and in the case of load-shedding, the boiler is not affected; however, other operations relying on the grid are affected. As we understand, coal is the cheapest source of energy in South Africa compared to other energy sources (diesel or gas), and the largest contributor to releasing carbon dioxide to the environment. It was also indicated that

coal is the cheapest fuel, so the hospital uses coal in the boiler house due to budgetary constraints. The details of the cost of coal were provided for the Gauteng Hospitals for comparison purposes.

A question was asked: What is the boiler maintenance process? Below is a summary of the responses from the engineer's maintenance personnel and the boiler operator.

Maintenance of the boiler includes ensuring that it properly functions every day. The process involves making sure that the water level indicator, safety valve, pressure gauge, etc., are all fully functional. The boiler cannot function safely without these elements. These fittings mounted on the steam boiler are required mandatorily for the safe and proper operation of the boiler system. These systems also require compulsory daily maintenance, a 36-month inspection, and a 12-month inspection. During the inspections, the boiler is switched off to maintain the water level indicator, safety valve, and pressure gauge.

A follow-up question was asked on how different the gas boiler is from the coal boiler in terms of functioning.

The engineers indicated that gas boilers operate the same way (in terms of concept) as coal boilers. Gas boilers combust natural gas or LPG in a burner, where gas is mixed with air in controlled proportions before combustion. Gas combustion is cleaner; you do not see the flame; it is controlled in the boiler.

According to Zhang 2013, the entire combustion process is carried out quickly and accurately in the gas-fired boiler to ensure efficient energy conversion, maximize fuel energy use, and provide a stable heat source for the heating system (Zhang, 2013). This is the main difference between the coal and gas boiler; the gas boiler maximizes thermal efficiency while producing enough steam, reducing emissions, and ensuring equipment reliability (Zhang,2013).

4.6 Cost of energy (Coal and Natural Gas)

According to the energy price report (DMRE, 2021), coal makes up about 57% of South Africa's primary energy supply. Of the total supply available for the country, 83%, is used in the transformation stages, where the majority is used to produce electricity (74%), while 26% is used

to produce petroleum products (Sasol) (DMRE, 2021). While the three largest users of natural gas are industrial, domestic, and power generation, the use of natural gas for power generation has risen the quickest (DMRE,2021). As regulated by NERSA, the cost of coal was R150 rands per Gigajoule, while that of gas averaged R143.14 per Gigajoule in 2021. These prices exclude VAT and transportation costs.

During the interview with the engineer, information on the cost of fuels used by the boilers was supplied to the researcher. Below are the annual cost hospitals spending on coal compared to natural gas. The reason for the comparison is that hospitals operate within strict budgets, and the affordability of energy directly impacts their financial sustainability. Coal is traditionally less expensive upfront but comes with hidden costs such as maintenance, handling, ash disposal, and penalties for high greenhouse gas (GHG) emissions. Natural gas, while typically more expensive per unit of energy, may offer long-term savings due to its efficiency and lower operational costs. The comparison is for the Gauteng hospitals, which gives a full view of the comparative cost. The information in Table 5 is the cost of coal in hospital compared to table 6 which is the cost of natural gas in Gauteng Hospitals.

Table 5: Expenditure on coal in the year 2021 (Department of Infrastructure)

Estimated Coal Prices			
Institution	Coal GJ /a	Estimated Coal Rate / GJ excl. VAT	Total Coal Cost (R) excl. VAT
Carltonville Hospital	33 916.00	150	5 087 400.00
Johan Heyns CHC	20 916.80	150	3 137 520.00
Heidelberg Hospital	33 916.00	150	5 087 400.00
ODI Hospital	52 836.40	150	7 925 460.00
Sterkfontein Hospital	33 916.00	150	5 087 400.00
Tambo Memorial Hospital	42 973.60	150	6 446 040.00
Jubilee Hospital	43 091.60	150	6 463 740.00
Kalafong Hospital	66 201.20	150	9 930 180.00
Leratong Hospital	43 091.60	150	6 463 740.00
Masakhane Laundry	132 402.80	150	19 860 420.00

Weskoppies Hospital	33 916.00	150	5 087 400.00
Sebokeng Hospital	52 836.40	150	7 925 460.00
Pholosong Hospital	33 916.00	150	5 087 400.00
Far East Rand Hospital	43 091.60	150	6 463 740.00
Steve Biko Hospital	132 402.80	150	19 860 420.00
Dr. George Mukhari Hospital	132 402.80	150	19 860 420.00
Dunswart Laundry	132 402.80	150	19 860 420.00
Pretoria West Hospital	33 916.00	150	5 087 400.00
Dr Yusuf Dadoo Hospital	33 916.00	150	5 087 400.00
Kopanong Hospital	52 836.40	150	7 925 460.00
Discovery Hospital	33 916.00	150	5 087 400.00
Tembisa Hospital	42 973.60	150	6 446 040.00
Rahima Moosa	52 836.40	150	7 925 460.00
South Rand Hospital	33 916.00	150	5 087 400.00
Hellen Joseph Hospital	52 836.40	150	7 925 460.00
Edenvale Hospital	94 314.80	150	14 147 220.00
Institute (TMI)	132 040.80	150	19 806 120.00
Total			**244 159 920.00**

The table above shows that the hospital with the highest consumption is paying approximately R19.8 million rands per year for fuel to operate the boiler. Helen Joseph Hospital consumes approximately R7.9 million annually in coal expenditure for its steam requirements. This excludes the boiler maintenance cost and the human capital that manages the coal boiler. This also excludes the cost of electricity, which is paid to city power over and above the fuel cost.

Health institutions also have gas boilers, which operate depending on the availability of gas and the budget required to procure gas. The table below shows the estimated gas consumption measured in Gigajoules per annum for the year 2021. However, the hospitals have since stopped gas procurement due to expired gas supply contracts. The Helen Joseph Hospital spent approximately R7.5 million on Liquified Natural Gas (LPG) which was used to operate the natural

gas boiler, which was supplied to the institution. Table 6 below shows the expenditure on natural gas for the year 2021 for some Gauteng hospitals.

Table 6: Cost of gas per GJ per annum for the 2021 year.

Gas Prices					
Institution	**Contracted Gas Volumes GJ /a**	**% Used GJ/a**	**Actual Volumes GJ/a**	**Gas Rate per GJ/an excl. VAT**	**Total cost/a (R) excl. VAT**
Carltonville Hospital	84 790.00	0.4	33 916.00	209	7 088 444.00
Johan Heyns CHC	52 292.00	0.4	20 916.80	209	4 371 611.20
Heidelberg Hospital	84 790.00	0.4	33 916.00	209	7 088 444.00
ODI Hospital	132 091.00	0.4	52 836.40	209	11 042 807.60
Sterkfontein Hospital	84 790.00	0.4	33 916.00	209	7 088 444.00
Tambo Memorial Hospital	107 434.00	0.4	42 973.60	209	8 981 482.40
Jubilee Hospital	107 729.00	0.4	43 091.60	265.8	11 453 747.28
Kalafong Hospital	165 503.00	0.4	66 201.20	265.8	17 596 278.96
Leratong Hospital	107 729.00	0.4	43 091.60	265.8	11 453 747.28
Masakhane Laundry	331 007.00	0.4	132 402.80	265.8	35 192 664.24
Weskoppies Hospital	84 790.00	0.4	33 916.00	263	8 919 908.00
Sebokeng Hospital	132 091.00	0.4	52 836.40	263	13 895 973.20
Pholosong Hospital	84 790.00	0.4	33 916.00	158	5 358 728.00
Far East Rand Hospital	107 729.00	0.4	43 091.60	175	7 541 030.00
Steve Biko Hospital	331 007.00	0.4	132 402.80	175	23 170 490.00
Dr. George Mukhari Hospital	331 007.00	0.4	132 402.80	175	23 170 490.00
Dunswart Laundry	331 007.00	0.4	132 402.80	158	20 919 642.40
Pretoria West Hospital	84 790.00	0.4	33 916.00	175	5 935 300.00
Dr Yusuf Dadoo Hospital	84 790.00	0.4	33 916.00	205.2	6 959 563.20
Kopanong Hopsital	132 091.00	0.4	52 836.40	205.2	10 842 029.28
Discovery Hospital	84 790.00	0.4	33 916.00	205.2	6 959 563.20
Tembisa Hospital	107 434.00	0.4	42 973.60	205.2	8 818 182.72
Rahima Moosa	132 091.00	0.4	52 836.40	143.14	7 563 002.30

South Rand Hospital	84 790.00	0.4	33 916.00	143.14	4 854 736.24
Hellen Joseph Hospital	132 091.00	0.4	52 836.40	143.14	7 563 002.30
Edenvale Hospital	235 787.00	0.4	94 314.80	143.14	13 500 220.47
Institute (TMI)	330 102.00	0.4	132 040.80	142.14	18 768 279.31
Total					**316 097 811.58**

Figure 11 below shows the cost of coal compared to natural gas. The financial figures are derived from the table above and plotted on the graph below.

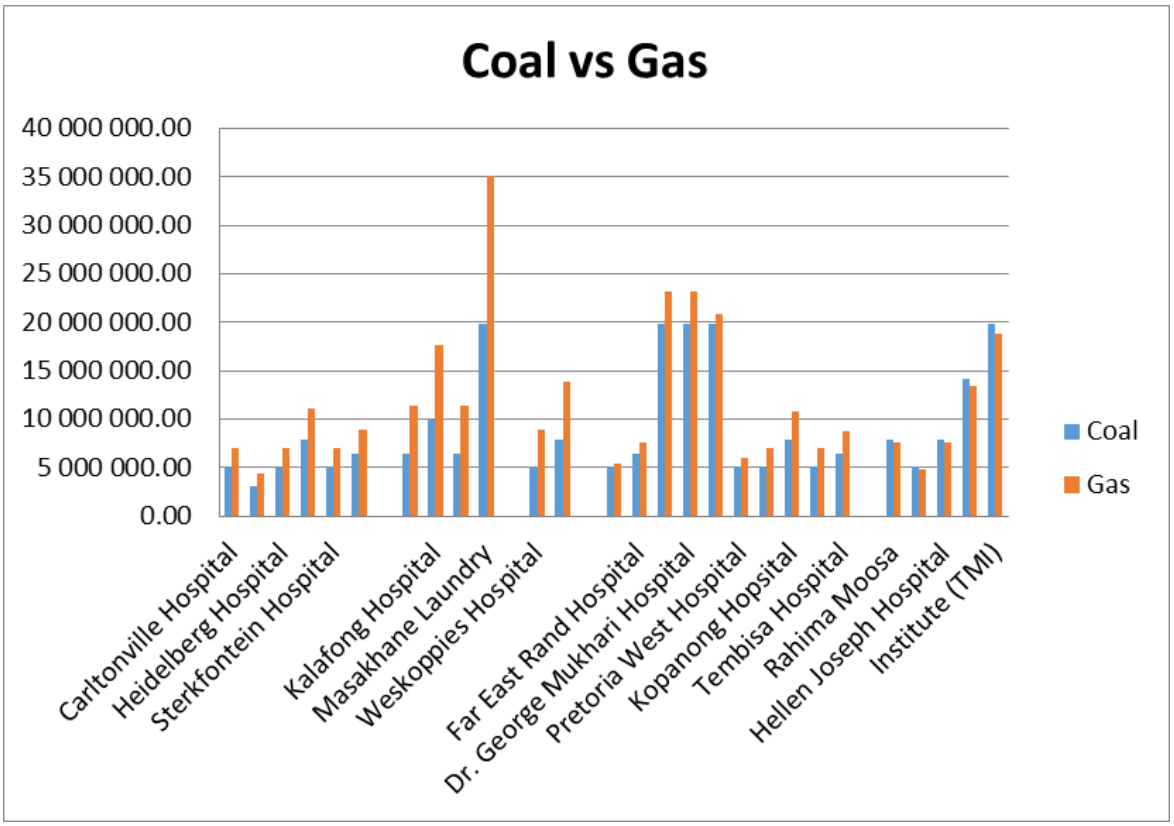


Figure 11: Cost comparison of coal vs gas in the institution. Figure 9 shows the graphical comparison of the cost of coal compared to natural gas per annum for the Helen Joseph Hospital only.

The figures above in Tables 5 and 6 indicate a gas cost per annum of approximately 4.6 % more than the cost of coal. Figure 12 below shows a pie chart of the comparison in cost of the fuels.

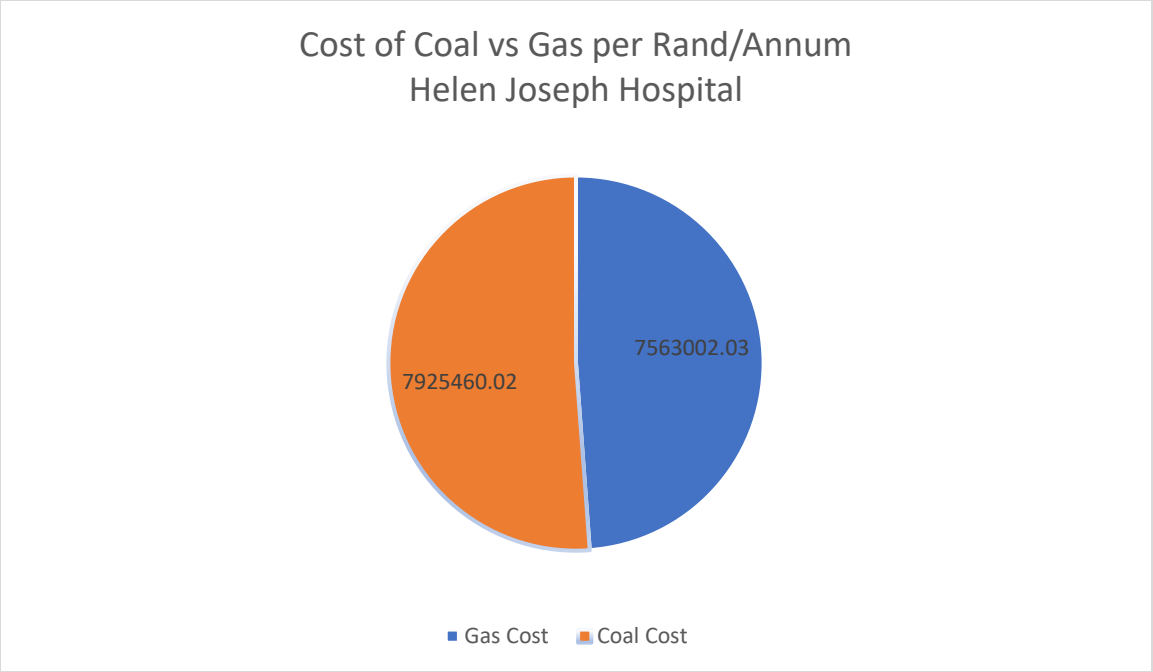


Figure 12: The cost of Gas vs Coal per annum for the Helen Joseph Hospital

The following question was asked: '*What percentage of the hospital's budget is spent on energy generation, and considering the current fiscal budget, how much would be suitable for installing an alternative energy system?*'

The response to this question from all the participants indicated that the Hospital budget is managed by the Management and Finance team in the institution in collaboration with the Health Head office; therefore, the technical teams do not necessarily contribute to the budget requirements or know how much is spent on energy generation. It was even noted that the hospital boilers consume coal, and the finance team pays for the services.

Very few respondents had positive opinions about alternative energy namely solar, natural gas, diesel or hydropower. However, there was uncertainties of job losses, uncertainties of theft as the hospital experiences a lot of theft and uncertainty of trailing out the technologies. These systems are highly digitized with a minimal requirement of operator skills and might render the boiler operators ineffective.

4.7 Cost of Electricity in the Hospital

During the interview of the engineers and facility managers, it was highlighted that the hospital has an excessive electricity bill serviced to city power, with disputes due to some bills being charged based on assumptions. The electricity is used to power all hospital energy requirements outside of steam, such as lighting, equipment, hostels, wards, etc. Below is an energy consumption analysis of the bill. A comprehensive bill analysis was done from May 2019 to September 2021 to track hospital consumption and determine the electricity baseline. Below is the electricity usage analysis. The information below came from the hospital bill and was analysed by the researcher. This information shows us the time-of-use tariff has three time periods, which include the peak, standard, and off-peak, and the associated cost. The breakdown of the usage is approximately 16% Peak, 39% Standard, and 45% Off-Peak. This breakdown of energy usage at Helen Joseph Hospital provides valuable insight into the hospital's energy expenditure patterns and can inform strategies for cost reduction and energy efficiency.

The Peak Consumption (16%) is during Peak hours represent the time when electricity prices are highest. During this period, the hospital can explore ways to reduce energy consumption through demand-side management strategies such as load shedding or load shifting, which could include optimizing equipment usage or scheduling energy-intensive tasks outside peak periods.

Standard and Off-Peak Consumption (39% & 45%) is during Off-peak hours, when electricity is cheaper, account for a large portion of the hospital's energy usage. The hospital could enhance its energy efficiency by aligning energy-intensive operations (such as sterilisation or laundry) with off-peak times, taking full advantage of lower rates. This information gives insight into the expenditure of the hospital on energy expenditure. The cost has tripled from May 2019 to September 2021 due to the increase in hospital wards hence the increase in expenditure and the increased cost of electricity.

Table 7: Energy usage from May 2019 – September 2021 (Department of Health)

kWh Usage	Peak	Cost	Standard	Cost	Off Peak	Cost	kWh	Costs
May-19	175 772,00	R236 219,99	428 719,00	R445 310,43	508 778,00	R406 208,36	1 113 269,00	R1 087 738,77
Jun-19	166 071,00	R233 113,86	423 464,00	R442 773,96	471 974,00	R377 720,79	1 061 509,00	R1 053 608,61
Jul-19	196 812,00	R632 750,58	499 334,00	R628 611,57	558 687,00	R454 882,96	1 254 833,00	R1 716 245,11
Nov-19	179 572,00	R280 114,36	427 839,00	R502 454,12	426 299,00	R384 862,74	1 033 710,00	R1 167 431,22
Dec-19	163 131,00	R254 468,05	407 734,00	R478 842,81	469 436,00	R423 806,82	1 040 301,00	R1 157 117,68
Jan-20	160 550,00	R250 441,95	404 972,00	R475 599,12	461 992,00	R417 086,38	1 027 514,00	R1 143 127,44
Feb-20	152 153,00	R237 343,46	369 898,00	R434 408,21	482 460,00	R435 564,89	1 004 511,00	R1 107 316,56
Mar-20	155 970,00	R243 297,60	388 100,00	R455 784,64	453 302,00	R409 241,05	997 372,00	R1 108 323,29
Nov-20	191 341,33	R298 473,34	445 549,54	R523 253,38	514 551,18	R464 536,80	1 151 442,05	R1 286 263,52
Dec-20	164 381,63	R256 418,91	381 955,48	R448 568,51	448 702,71	R405 088,81	995 039,82	R1 110 076,23
Jan-21	174 458,88	R294 538,92	402 572,01	R511 709,28	474 169,99	R463 311,50	1 051 200,88	R1 269 559,70
Mar-21	320 545,00	R541 176,12	792 183,00	R1 006 943,81	814 673,00	R796 016,99	1 927 401,00	R2 344 136,92
Apr-21	303 473,00	R512 353,47	780 507,00	R992 102,45	840 384,00	R821 139,21	1 924 364,00	R2 325 595,12
May-21	312 629,00	R527 811,54	775 107,00	R985 238,51	856 577,00	R836 961,39	1 944 313,00	R2 350 011,44
Jun-21	336 141,00	R592 751,04	812 362,00	R1 039 498,41	1 024 782,00	R1 003 773,97	2 173 285,00	R2 636 023,42
Jul-21	428 943,00	R1 731 557,10	1 051 019,00	R1 620 040,69	1 114 353,00	R1 176 868,20	2 594 315,00	R4 528 465,99
Aug-21	414 250,00	R1 906 958,45	1 018 403,00	R1 789 945,11	1 130 709,00	R1 361 599,78	2 563 362,00	R5 058 503,34
Sep-21	397 035,00	R1 793 526,20	963 971,00	R1 684 924,91	1 210 784,00	R1 454 756,97	2 571 790,00	R4 933 208,08

Below is a graphical representation of energy usage between May 2019 and September 2021. Some months are missing due to unavailable energy bills.

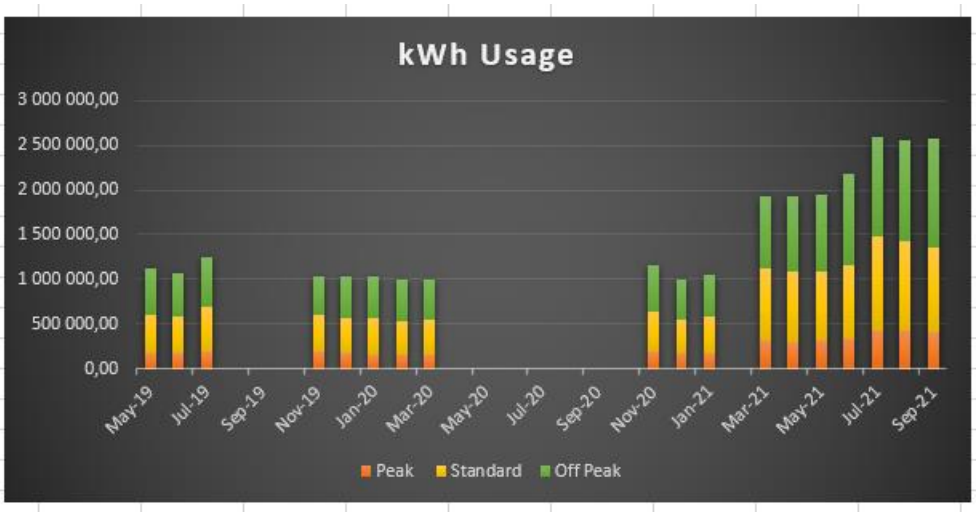


Figure 13: Graphical analysis of KWh energy usage

4.8 Environmental Impacts of Coal vs Gas Boilers

During the interview with the engineers and boiler operators, they alluded to the environmental impacts of coal boilers. These general environmental impacts affect human beings even though the actual impact not measured. They explained that they understand that the *coal being burnt primarily consists of carbon, sulfur, and nitrogen. Therefore, the combustion products include high*

nitrogen oxides and sulfur oxides. Fly ash and particulate matter are also produced during combustion. The major problem with coal-fired boilers is the handling of fly ash; fly ash is made of fine particles that are easily carried away by the flue gases and contaminate the surrounding areas with fly ash.

Natural gas used in the gas boiler is the cleanest of all fossil fuels, mainly comprised of methane, and the products of combustion of natural gas include mainly carbon dioxide and water vapor sulphur dioxide, and nitrogen oxides in smaller quantities. Also, the combustion of natural gas does not leave any fly ash or any other particulate matter. Because of this, natural gas boilers have the advantage of reducing pollutants and maintaining a clean environment when compared to coal-fired boilers.

The Boiler Operators also mentioned that the ash residue from the combustion of coal is required by law through the National Environmental Management Act (NEMA) 107 of 1998 to be collected and disposed of. As with the rest of the handling and treatment process, coal ash is collected either in dry or wet form. Dry ash collection allows for the most control over how the waste is eventually handled, but it's more expensive to install and maintain. Extra air volume is necessary to move all the fly ash through filters, so it does not escape through the vents or clog the system. Wet ash collection is common because rinsing out the ash also doubles as a cooling tower treatment method for achieving power generation goals. However, this means that extensive dewatering is necessary to achieve dry ash waste again if it's preferred.

4.9 Decarbonisation Strategies of the Hospital

The Gauteng Energy Security Strategy of 2011 is among the policies that encourage the decarbonisation of public hospitals in Gauteng (Energy Security Strategy,2011). The policy encourages the uptake of renewable and alternative energy; however, this policy is not binding for the Hospital. It is important that a green hospital policy becomes binding and has targets for each building. According to Renjitha (2021), a green or sustainable building is the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials and reducing building impacts on human health and the environment through better siting, design, construction, operation, maintenance, and removal during the complete building life

cycle. A green Hospital aims to reduce negative environmental impacts and upgrade public health (Renjitha,2021). A question was asked: "*Based on the hospital's climate change plans, what are the possibilities for centralised energy generation (boiler house) to be replaced by a more sustainable option?*

It was highlighted in all 15 responses that a huge variety and complexity of buildings and heating systems within the hospital system present a significant challenge to the decarbonisation of heat generation. Many hospitals constructed more than 20 years ago use steam for space and hot water heating, as well as for some sterilisation and humidification processes. Infrastructure development and upgrading to support health services in primary healthcare facilities is an important step in the journey toward decarbonisation (Duindam,2022). Steam heating systems are usually powered and require high-pressure conditions to be maintained throughout the network (ibid). The Engineers mentioned that the issue with decarbonising the system will require a capital investment in infrastructure upgrades. Investing in infrastructure upgrades for green hospitals involves capital expenditure aimed at improving sustainability while enhancing the quality of patient care (Duindam, 2022). The challenges faced by the hospital, such as unreliable water supply, overcrowding of patients, procurement of medications, health litigations, corruption, and mismanagement of funds, etc., exhaust the budget and therefore have caused the status core of the use of fossil fuels to remain.

This information helps answer the question, "*How can transitioning to natural gas-fired systems contribute to the long-term sustainability of public health facilities?* Part of the finding is that public hospitals have old, dilapidated infrastructure, which is common across the whole property portfolio. Part of the Roadmap to decarbonize the hospitals must include prioritizing infrastructure upgrades for energy efficiency, water efficiency, waste management and recycling, green building design, and retrofitting of renewable energy sources.

The respondents also highlighted the challenge of losing jobs through the decarbonisation process. It was highlighted that every hospital is different, with different infrastructure and secondary systems, different levels of service provision, and different building designs in varying

types of locations. Every hospital needs its own bespoke zero-carbon roadmap or decarbonisation plan (Duindam,2022).

The decarbonisation plan for the Helen Joseph Hospital is a two-fold n which aims at decarbonising the hospital including transition to Natural Gas which was done but not utilised to its full capacity. Natural gas is a cleaner-burning fuel that reduces CO_2 emissions by approximately 50% compared to coal. The Hospital has a plan to Integrate of Renewable Energy by Installing photovoltaic (PV) panels for electricity generation and solar water heaters for thermal energy needs. Finally implementing energy efficiency by conduct an energy audit to identify inefficiencies then upgrade to energy-efficient appliances, LED lighting, and HVAC systems and finally Implement smart energy management systems to monitor and optimize energy use. This is the hospitals plan however the implementation highly depends on the DID on behalf of health as the DID is the infrastructure implementing agent for Helen Joseph Hospital.

4.10 Conclusion

The sub-findings presented in this chapter answer the question " *What technical and institutional barriers exist in the transition to natural gas-fired systems at Helen Joseph Hospital and how can these* barriers be addressed to encourage adoption? Throughout the interview process and the site visits it was observed that the transition to natural gas-fired systems at Helen Joseph Hospital is impeded by several technical and institutional barriers. Technically, the hospital's existing infrastructure is designed for coal-fired operations, even though one boiler was converted to gas. This is observed at the boiler house where the hospital still requires significant retrofitting or replacement of the equipment to accommodate natural gas. The fuel gas feeders, control system and combustion chamber design still put coal as the primary fuel in the boiler house. Additionally, limited access to natural gas infrastructure and supply further complicates the transition. The hospital has a direct connection to existing gas pipelines which belong to Egoli Gas however still requires substantial investment in owning and not renting the pipeline.

Institutionally, the high upfront costs of transitioning, coupled with financial constraints within the public healthcare sector, act as a significant barrier.

Addressing these barriers requires a multi-faceted approach. Developing a phased infrastructure upgrade plan, securing long-term natural gas supply contracts, and providing training programs for technical staff can mitigate technical challenges. Financially, government subsidies, public-private partnerships, and environmental grants can ease the capital burden. Clear policy incentives, such as tax breaks and carbon credits, along with stakeholder engagement to highlight the benefits of cleaner energy, can encourage institutional support. By combining technical solutions with institutional reforms, the hospital can facilitate a sustainable and cost-effective energy transition.

Consistent with Al-Rawi (2023), hospitals and healthcare facilities require various engineering services, including heat ventilation and air conditioning systems, hot and domestic water supply systems, and backup electricity systems (Al-Rawi,2023). These energy-intensive services offer an excellent opportunity to integrate renewable energy sources and reduce the carbon footprint of healthcare facilities; however, each healthcare facility requires its own customized decarbonisation process that will lead to a green hospital (Al-Rawi, 2023).

Respondents in the interviews raised important points about the dilapidating infrastructure in the hospital, the operations of a coal boiler, and the environmental hazards of generating steam using a coal-fired boiler. The responses received indicate that public hospitals have a general common challenge of high steam consumption, high electricity consumption, lack of finances to spend on decarbonisation initiatives, the absence of suitable infrastructure is another crucial barrier to decarbonisation, managerial issues, including lacking management support for decarbonisation initiatives and employee resistance to change are recognized barriers. However, the business model of government, which involves planning, budgeting operations, and implementation done at different entities without synergy, causes the disjuncture in managing the energy transition. The hospital has the potential to decarbonize; however, this is highly reliant on individual barriers being addressed.

CHAPTER 5 BARRIERS TO DECARBONISING THE CENTRAL GENERATING SYSTEM

5.1 Introduction

This chapter presents the data and analyses in response to sub-questions 1 to 3, which elaborate on the barriers to decarbonising the central generation system at Helen Joseph Hospital. The analyses give us a set of guiding principles for decarbonising the central generating system for healthcare facilities. These barriers include the lack of government policy on sustainability for hospitals, the administration model of hospitals, budget, and social factors such as lack of awareness on decarbonisation and change management.

5.2 Discussion of research sub-questions

What technical and institutional barriers exist in the transition to natural gas-fired systems at Helen Joseph Hospital and how can these barriers be addressed to encourage adoption?

This question was aimed at understanding the specific technical and institutional hurdles preventing or complicating the adoption of natural gas systems and to explore actionable strategies to overcome these barriers and facilitate the transition. The key areas of focus include understanding whether current coal-based systems can be retrofitted or if they need replacement will the hospital priorities the use of natural gas over coal?

5.2.1 Administration and Management of Public Hospitals

The administration of public hospitals is considered a barrier to the decarbonisation of the central energy-generating system at Helen Joseph Hospital. Public hospitals are administered as guided by the National Health Act 61 of 2003, which intends to provide a framework for a structured, uniform health system within the Republic of South Africa (Health, 2003). However, the hospital infrastructure is managed through an implementing agent which offers public works and engineering services to the hospital. According to Von Holdt (2010), large sections of the South African state, including public hospitals, are institutionally ineffective and dysfunctional and highly stressed institutions due to their management style (Von Holdt, 2010). This is due to the lack of autonomy, which means hospitals should be granted a degree of independence and self-governance in their operations, decision-making processes, and management practices. This

autonomy allows the hospital to function with greater flexibility and authority, often with reduced bureaucratic oversight from higher-level government or administrative bodies (Burnett et al., 2016). Managerial competence is crucial for institutions like hospitals, which must deal not only with healthcare-related issues but also infrastructure issues, given the budget and resource constraints.

Public hospitals in South Africa are typically overseen and funded by the government, primarily through the Department of Health at the National and Provincial levels. The National Health provides funding and manages policy, while the provincial government manages funding and operations of hospitals (Steward, 2019). The national government sets policies, regulations, and standards for hospital administration, as well as allocates budgets and resources to ensure the provision of healthcare services (ibid). The provincial government manages the hospital's administration, planning, and resource allocation. (Steward, 2019). The provincial government oversees infrastructure, public works, and engineering services in Gauteng. This causes a disjuncture in the hospital's management in that there is no autonomy in the institution. Hospitals have no control over their financial management, including revenue generation, expenditure planning, and budget allocation. This also includes decision-making and quality improvements in the hospital.

Infrastructure procurement or upgrades within each hospital must be done through the Infrastructure Delivery Management System (IDMS). In the case of Provinces, health Infrastructure Development is procured and managed by the Department of Public Works and Infrastructure (DPWI) or Infrastructure Development (DID) on behalf of the Department of Health (DoH). Hospital engineering staff propose designs for new builds or upgrades of infrastructure, which are procured through DPWI or DID and then implemented in the hospital. This model has been criticized for delaying infrastructure delivery or upgrades. The budget thereof for infrastructure is transferred to the infrastructure institution to manage on behalf of health.

Hospital management teams include administrators, medical directors, nursing directors, finance managers, and other key personnel (Fusheini,2016). These professionals are responsible for day-to-day operations, strategic planning, budget management, and ensuring the delivery of quality

healthcare services (Fusheini,2016). Respondents during the in-depth interviews revealed that executives and top management mostly carried out strategic planning, and hospitals cannot plan for their own energy management or transition with very little involvement from lower management or employee levels.

A neoliberal system in the context of hospitals might be required, as the healthcare system is characterized by neoliberal economic principles and policies (Sakellariou,2017). In a neoliberal healthcare system, hospitals may operate as profit-driven enterprises, competing for patients, contracts, and revenue streams (Sakellariou,2017). As Sakellariou (2017) argued, market mechanisms, such as price competition and consumer choice, may influence resource allocation and service delivery within hospitals. This might be a model of consideration to improve hospital funding and operational models. However, this model needs to accommodate even the poor (Sakllariou,2017).

Looking at the interview responses of the boiler operators, the majority were not aware of the budget for infrastructure and boiler operations. In the opinion of the researcher, the plan for decarbonisation of the central generating system should be done from a bottom-up approach as opposed to a top-down approach.

5.2.2 Budget Constraints

Nearly all respondents at all levels of management highlighted budgetary constraints as an influencing factor against achieving the core mandate of the hospital, which is quality healthcare.

The hospital has budgetary constraints on all aspects. We rely on how much of a budget was given in Parliament and provincially and to the institution. Budget is a huge problem. Why I said budget is a huge problem is that, for instance, the maintenance budget is centralised, it is at a district office, while the budget for infrastructure is at an implementing agent and that of healthcare is at the hospital.

A major consequence of these budgetary constraints is the inability to plan and manage infrastructure improvements and maintenance. This poses a debate on whether the public health

care system should be neoliberal and profit-driven to provide quality infrastructure, sustainability, and quality health care.

5.2.3 Employment uncertainties

Uncertainty brings about numerous problems relating to asymmetric information, risk aversion, and, thus, fear of employment uncertainties (Ivanovski,2021). It was noted during interviews that some professionals prefer to work and operate coal boilers because of job security issues, as gas boilers and renewable energy systems are digitized and require minimal human operation. This suggests a resistance to change within the organization and the hesitance to adopt and work with new technologies due to a lack of knowledge (Ivanovski,2021). The researcher also noted that the interviewed staff were very concerned about reliability, effectiveness, or disruption to existing operations, especially in a health facility where any operational uncertainty can affect patients.

There was a lack of awareness or understanding about the benefits of sustainable energy solutions in the long term. Some interviewees knew of renewable energy options such as rooftop solar and battery storage or alternative energy such as gas or diesel. However, there is an opportunity for awareness so that they are fully informed about the potential cost savings, environmental benefits, and health advantages associated with transitioning to renewable energy sources.

During interviews, management indicated that hospitals also do not prefer long-term contract agreements due to previous experiences where it is difficult to switch to alternative energy sources until these contracts expire or are renegotiated. This indicated that the hospital prefers flexibility in its energy procurement to adapt to changing energy market conditions, technological advancements, and sustainability goals.

5.3 Discussion of research sub-question 2

How can transitioning to natural gas-fired systems contribute to the long-term sustainability of public health facilities?

This research question sought to compare coal boilers and gas boilers to understand their performance, efficiency, emission level, effectiveness of the systems and contribution to the long-term sustainability of hospitals.

5.3.1 Coal boilers compared to gas boilers.

Below is the response provided by engineers on the difference between coal and gas boilers:

The engineers indicated that the gas boiler does not operate the same way as the coal boilers. The basic working principle of a gas-fired boiler is based on burning gas in the furnace to release high-temperature heat energy. By heating the water in the boiler, the water is heated and evaporated, and finally, stable and controllable steam is produced. This thermal energy conversion process mainly involves two key aspects: the combustion process and thermal energy conversion.

The entire combustion process is carried out quickly and accurately in the gas-fired boiler to ensure efficient energy conversion, maximize the use of fuel energy, and provide a stable heat source for the heating system. This is the main difference between the coal and gas boiler; the gas boiler maximizes thermal efficiency while producing enough steam, reducing emissions, and ensuring equipment reliability.

It was highlighted in the responses to the interviews that, according to Kras (2011), coal-fired boilers emit higher levels of greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NOx) compared to gas-fired boilers. These emissions contribute to air pollution, acid rain, and climate change (Kras,2011). Coal combustion also produces ash and other pollutants that can contaminate soil, waterways, and ecosystems, leading to negative environmental impacts (Kras, 2011). The hospital management respondents indicated that their concern is that these emissions happen inside the hospital facility, which poses a risk to patients and staff's health. The current emissions from Coal are estimated at 13,278.7 tCO_2e/year and this represents the annual carbon dioxide equivalent (CO_2e) emissions from the hospital's current coal-fired operations. The Projected Emissions from Natural Gas are 4,685 tCO_2e/year. If the hospital transitions to natural gas, emissions will decrease by approximately 65% compared to coal-fired operations. Therefore, the emissions reduction potential would be 8,593.7 tCO_2e/year

Switching to natural gas would prevent the release of over 8,500 tons of CO_2e annually, significantly contributing to the hospital's decarbonisation goals. This indicates that the measurement of the total GHG emissions from the boiler house caused directly by the organisation is expressed as a carbon dioxide equivalent (CO_2 e).

5.3.2 Efficiency and reliability

The engineers indicated to the researcher that Gas-fired boilers are generally more efficient than coal-fired boilers, meaning they can produce the same amount of energy with less fuel consumption. This higher efficiency can lead to cost savings and reduced operational expenses for hospitals (Srinivas et al., 2017), as coal has other hidden costs that must be considered. The ash is one of the factors that an administrator can overlook when a decision is to be made (Srinivas et al., 2017). Coal-fired boilers have numerous rotating equipment as part of the boiler to support combustion with decreased operability, and many resources are needed due to their complexity (Srinivas et al., 2017). Coal as a source of energy can have a detrimental effect on the boiler efficiency. It can build a slag on the boiler, affecting heat transfer due to wrong operating parameters and incorrect specification of coal qualities in the long run, which harms the equipment availability. Ash slag deposits inside the boiler furnace are a big challenge to the heat exchange tubes as they cause creep in the metal, thus compromising the equipment (Glushkov et al., 2023). Stevick (2020) indicates that a natural gas-fired boiler has fewer auxiliaries in comparison to coal-fired boilers as these boilers are complex and have more auxiliaries, hence low operability. More resources are needed to ensure the smooth operation of the boiler.

5.4 Discussion of research sub-question

What are the operational inefficiencies, environmental impacts, and energy outputs of existing coal-fired central generating systems in public health facilities?

This research question aimed at identifying the negative impacts (although not measured) of coal and the minimization of environmental harm.

5.4.1 Negative contribution of coal boilers

The general environmental impacts of coal utilization mainly result from the emission of air pollutants from combustion (Vamvuka, 2000). These pollutants may be distributed over a relatively large area, whose extent depends upon the combustion process's design and mode of operation (Vamvuka,2000). The various impacts on air, land, and water can result in damage to plant and animal species and their habitats, as well as modification or elimination of ecosystems (ibid)

The water consumption from coal boilers at the Helen Joseph Boiler uses an estimated amount of approximately four (4) gallons per hour per horsepower of the water used by a steam boiler, which is 8000kg/h. However, gas boilers require a minimal amount of water. This helps conserve water resources, particularly in regions prone to water scarcity or drought.

Coal boilers, which are fossil fuel-based, still need to be considered for waste management and disposal (Lowell,2010). As the process of generating steam happens, the coal boilers produce fly ash, which must be disposed of. At Helen Joseph Hospital, the 8000 kg boiler produces 1200kg of fly ash during its single operation. Furthermore, Lowell (2010) emphasizes that coal waste constitutes substantial matter to which the natural environment is susceptible, and its consequences are detrimental, resulting in soil leach and groundwater contamination.

5.5 Theory of Change in Hospital

According to Hussain et al. (2018), the theory of change can be defined as the management tool, which is an outcome-based approach that applies critical thinking to the design, implementation, and evaluation of initiatives and programs intended to support change in their context (Hussain et al., 2018). The theory of change includes analysing how intervention-created change might happen and how it should happen (Hussain et al., 2018).

This theory includes the current state of the problem, the actors to influence change, the outcome of desired long-term change, a description of the process of change, and the underlying assumptions (Hussain et al., 2018). For the theory of change to be effective, change management must happen in an organization, which can be defined as a process of continually renewing an

organization's direction, structure, and capabilities to serve the needs of its customers (Hussain et al., 2018).

The socio-technical transition theory, or socio-technical systems theory, provides a framework for understanding and analysing change between the complex interplay between social and technical factors in shaping transitions toward sustainable energy systems (Cherp, 2018). This theory recognizes that energy transitions involve not only technological innovations but also changes in social practices, institutions, behaviours, and cultural norms (Cherp,2018)

The MLP framework, developed by Frank Geels, is a central concept in socio-technical transition theory. It distinguishes between three analytical levels: niche innovations, socio-technical regimes, and socio-technical landscapes (Cherp, 2018). Niche innovations represent novel technologies, business models, or practices emerging at the margins of existing systems (Cherp, 2018). Meanwhile, socio-technical regimes encompass dominant structures, rules, and practices governing energy systems. Socio-technical landscapes encompass broader societal, cultural, economic, and political contexts influencing transitions (Cherp, 2018). Transitions occur through interactions and tensions between niche innovations challenging established regimes within evolving landscapes.

Applying socio-technical transition theory to energy transition leads institutions to gain insights into the dynamics, barriers, and opportunities associated with shifting towards sustainable energy systems. This holistic approach helps identify leverage points for intervention, foster innovation, and promote socio-technical transformations toward more resilient, equitable, and environmentally sustainable energy futures (Cherp, 2018). Helen Joseph Hospital has the potential to achieve a complete energy transformation by applying the Theory of Change and the socio-technical transition framework. This approach can help identify critical leverage points for intervention, drive innovation, and support socio-technical transformations toward more resilient, equitable, and environmentally sustainable energy solutions for the institution.

5.6 Integrated Renewable Energy Resource Efficiency Program (IREREP)

The National Department of Public Works (DPWI) is the major custodian of public sector buildings in South Africa (National Department of Public Works, 2004). It is also the largest property

portfolio manager in the Southern Hemisphere, with more than 92,000 facilities, which equate to 37 million square meters (sqm), valued at more than R120 billion and requiring an operating expenditure budget of at least R6 billion per annum (De Lille, 2022). The DPWI is responsible for maintaining the property portfolio as guided by the Government Immovable Asset Management Act (GIAMA), No 19 of 2007 (GIAMA), which seeks to introduce measures to ensure a uniform framework for the management of immovable assets that are used by (or is reserved for) a national or a provincial department in support of its service delivery objectives (Government Gazette, No, 1124, 2007).

The DPWI finds it challenging to manage their buildings effectively and optimally due to a lack of Building Management Systems (BMS) (hardware and software) which are not in place, and there is a lack of updated information on the status of the buildings. The property portfolio has no credible baseline data for energy, water, and waste to ensure adequate resource efficiency, routine maintenance, and reduction of excessive consumption.

The world at large is experiencing an increase in population growth and economic activities, hence an increase in energy demand and consumption (Harish and Kumar, 2016). Increased energy consumption continues to exacerbate greenhouse gas (GHG) emissions, which have serious environmental, economic, and social impacts on the global environment. The expected increase in energy demand, with the predominance of coal in the energy mix, highlights the significance of promoting energy efficiency, particularly in sectors such as the built environment (Harish and Kumar, 2016).

The Integrated Renewable Energy Resource Efficiency Program (IREREP) holds immense potential to transform hospitals and other public buildings managed by the Department of Public Works and Infrastructure (DPWI). By addressing critical challenges and harnessing renewable energy and resource efficiency measures, the program aims to modernize public infrastructure while promoting sustainability (IREREP,2021).

IREREP seeks to overcome the current inefficiencies within DPWI's extensive property portfolio, including the lack of Building Management Systems (BMS), outdated infrastructure, and the absence of credible baseline data for energy, water, and waste consumption. The program will

establish advanced monitoring and management systems, enabling real-time tracking and optimization of resource use, thereby reducing excessive consumption and operational costs.

Through the integration of renewable energy sources such as solar panels, wind turbines, and energy storage solutions, IREREP will reduce dependency on coal-dominated energy supplies. This shift not only aligns with global decarbonization goals but also enhances energy security for critical facilities like hospitals, ensuring uninterrupted operations and improved service delivery (IREREP,2021).

Additionally, the program emphasizes water efficiency through rainwater harvesting, greywater recycling, and the installation of water-saving fixtures. It also promotes sustainable waste management practices, minimizing environmental impact and contributing to the broader objectives of a circular economy. By implementing these strategies, IREREP will enable hospitals and public buildings to operate more efficiently, reduce greenhouse gas emissions, and achieve significant cost savings. This transformation aligns with the DPWI's mandate to manage public assets responsibly and supports South Africa's commitment to a sustainable and low carbon future (IREREP,2021).

5.7 Proposed recommendations to enhance adoption of alternative energy at Helen Joseph Hospital

5.7.1 Recommendations for Helen Joseph Hospital scenario

Recommendations for the National Department of Health to address the Energy Transition policy and implementation gap in the integration of the hospital. The provincial government and national government, particularly in view of the key roles these stakeholders will play in driving the energy transition.

Acknowledge hospital management and leadership as key drivers of hospital performance in energy transition. As part of effective hospital governance, hospital systems must be supported in formulating decarbonisation development strategies.

It was evident from the analysis of the energy bills and the cost thereof that Helen Joseph Hospital is unaware of its baseline and energy consumption patterns. It is recommended that the hospital installs a check meter to verify the bill charges from the city council and to establish a reliable baseline to help measure energy consumption.

The hospital will have to conduct change management strategies to educate and communicate to its employees and service providers effectively. This strategy can reduce employees' fears and uncertainties. During the interviews boiler operators indicated that they prefer to work on coal boilers rather than gas boilers due to the fear of job uncertainty. When an energy plan is communicated, and employees can be reskilled to manage alternative energy systems that are highly digitised.

Behaviour changes and improved attitudes towards sustainability could be a powerful accelerator of the changes required to decarbonize health institutions. More positive attitudes towards decarbonisation would lead to the implementation of policies at a hospital level and drive change in other aspects, such as pressuring supply chains and energy companies to decarbonize.

Energy transitioning through a bottom-up approach for energy transition involves empowering employees and stakeholders. Fostering active engagement and participation of employees in energy transition initiatives. Provide education, training, and capacity-building programs to empower staff members to implement sustainable practices.

During the interviews, a question was asked: What are the possibilities for centralised energy generation (boiler house) to be replaced by a more environmentally friendly option? Approximately 14 of the 15 respondents did not know what the hospital plans were in relation to the decarbonisation of the central generating system. It is therefore recommended that the hospital develop an autonomous energy plan that includes clear energy transition goals. This plan should be developed, managed, and implemented by the hospital.

It is recommended that the hospital invest in its own decarbonisation process. This investment could be coupled with prioritizing energy efficiency measures alongside alternative energy projects to maximize energy savings and reduce overall consumption. This may include upgrading

lighting systems, optimizing HVAC systems, and implementing energy-efficient appliances and equipment. This has the potential to holistically improve the overall consumption.

5.8 Conclusion

This chapter presented a discussion of the study's results, highlighting several barriers to the adoption of natural gas within the central generation system. These barriers include inefficient administration in public hospitals, budgetary constraints, a lack of awareness, inadequate planning, and prevailing negative perceptions of renewable energy. Despite these challenges, the findings also emphasize the potential for overcoming these obstacles through targeted interventions, such as improving governance structures, increasing budget allocations, fostering capacity-building initiatives and enhancing awareness campaigns. Additionally, the integration of strategic planning and stakeholder collaboration can serve as a catalyst for accelerating the transition to sustainable and resilient energy solutions within the healthcare sector.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion and perspectives

This research study was aimed at investigating why there is low adoption of natural gas in the central generating systems in public hospitals. Hospitals are the second highest consumers of energy in the built environment, as they are regarded as being part of the commercial sector (Hohne et al., 2020). Most public hospitals rely on a central boiler system to generate steam, which is distributed to the various functional units, e.g., Sterilisation, Water Heating, and Cooking. The remainder of the hospital is supplied directly by electricity from the Eskom utility, which is used for lighting, therapy, and general usage (Cunningham, 2015). Boilers are the biggest single energy consumption item in hospitals. The centralised supply of heat proved to be the most efficient in the past, and many hospitals are equipped with coal boilers that operate 24 hours a day (Cunningham, 2015). However, this is no longer the most efficient method of energy generation in Health facilities. This study identified the barriers that have led to a low uptake natural gas over coal in the central generating system and recommendations formulated based on the findings.

The main research question states*, how can public health facilities transition from coal-fired to natural gas-fired central generating systems to improve energy efficiency, reduce environmental impact, and ensure sustainable and reliable energy generation?*" The administration of public hospitals has a direct impact on the energy transition within the hospital. Public hospitals in Gauteng are overseen and funded by the provincial treasury, primarily through the Department of Health. According to Von Holdt (2010), large sections of public entities, including public hospitals, are commonly ineffective and dysfunctional and highly stressed institutions due to their management style (Von Holdt, 2010). This is due to the need for more autonomy, which means hospitals have a limited degree of independence and self-governance in their operations, decision-making processes, and management practices. Based on the findings on administration and governance, it can be concluded that hospital management does not have full control of the hospital's infrastructure and energy projects as it is managed by a third party on its behalf. This influences the uptake of alternative energy. This means that the budget expenditure, project designs, and decisions are made on their behalf. The researcher believes the hospital can employ

alternative management styles, such as private finance initiatives, which involve contracting out the design, build, finance, and operation model.

The data analysis has shown that using coal heat and cooling in hospitals results in extreme environmental degradation. Research has shown that using alternative energy can lower the carbon footprint significantly. It was highlighted in the responses to the interviews that Coal-fired boilers emit higher levels of greenhouse gases such as carbon dioxide (CO_2), sulfur dioxide (SO2), and nitrogen oxides (NOx) compared to gas-fired boilers. These emissions contribute to air pollution, acid rain, and climate change. These emissions happen inside the hospital facility, which poses a risk to patients' and staff's health. It can be concluded that the hospital's significant reduction of the negative environmental impacts can decline significantly if the boilers use natural gas. This, in turn, lets us estimate the economic gain from the transition. There is a significant difference between the value of the socio-economic and environmental benefits and the net gain from finally ending our reliance on fuel. This will also eliminate flying ash, which needs to be disposed of, and the possibility of boiler operators being exposed to polluted air that can lead to respiratory diseases. It is recommended that awareness campaigns be conducted on renewable energy systems and the possible green jobs that are created in the process.

The capital cost of investing in gas infrastructure at Helen Joseph Hospital presents a significant challenge due to financial constraints. Even though the hospital has a natural gas boiler it is not fully utilised as the primary fuel is still coal. Establishing such infrastructure requires substantial upfront investments in pipeline installation, boiler conversion or replacement, storage facilities, and auxiliary systems, all of which demand considerable funding. Furthermore, the hospital must account for additional expenditures related to environmental compliance, safety measures, and technical training for operational staff. These financial demands are compounded by the already limited budgets allocated to public healthcare facilities, which prioritize immediate patient care needs over long-term infrastructural investments. As a result, the hospital faces difficulties in mobilizing the necessary resources to transition to gas infrastructure, despite the potential for long-term cost savings and environmental benefits. Addressing these constraints requires innovative funding solutions, such as public-private partnerships, government grants, or external

donor support, to enable the hospital to overcome these financial barriers and achieve sustainable energy goal.

Throughout the analysis of the results for research question 3, it was identified that there were multiple environmental effects of generating energy through an alternative energy system, including water conservation, waste management, health impacts, and emission reduction. While natural gas is seen that can help transition to a lower-carbon energy system, over-reliance on natural gas may delay the deployment of renewable energy and decarbonisation efforts. Without adequate measures to mitigate methane leakage and address environmental impacts, increased natural gas use may hinder long-term climate change mitigation goals. Overall, while natural gas may have lower emissions and environmental impacts compared to coal, it is not without its own environmental challenges. Effective mitigation strategies, regulation, and technological innovations are needed to minimize the environmental footprint of natural gas usage in boilers and ensure a sustainable energy future.

Although grid power remains a dominant mode of energy supply, at Helen Joseph Hospital in there is a huge opportunity to invest more thought and money in on-site power generators using an expanding array of energy technologies. These range from advanced Natural Gas technologies producing combined heat and power (CHP) to large- and small-scale PV solar systems. Driving this trend is the need of hospitals so that they provide first-line emergency and obstetrics services A backup power source is essential for any hospital handling childbirths, emergencies, day surgeries, vaccine storage or laboratories.

6.2 Recommendations

The use of natural gas for thermal heat (steam) generation in hospitals has been studied. Hospitals are big energy consumers, requiring continuously large amounts of energy throughout the year. The main alternative energy examined was the natural gas fuel. Based on the analysis of data conducted in Chapter 4 and discussions in Chapter 5, it can be recommended that public hospitals require the following interventions to improve the uptake of natural gas which include:

- A new management style such as the private finance initiative which gives the hospital autonomy to manage their own energy transition process.
- A policy implementation strategy that will encourage the implementation of climate change action in the hospital.
- An understanding of the energy profile and the bassline of the hospital to implement energy efficiency.
- Conduct change management and theory of change to support the energy transition process.
- Implement a private funding model to invest in their own decarbonisation process.

a) Adopting a New Management Style (Private Finance Initiative): Giving hospitals autonomy to manage their energy transition process through initiatives like the Private Finance Initiative (PFI) can empower them to make decisions tailored to their needs and circumstances. This can accelerate the adoption of renewable energy technologies, energy efficiency measures, and sustainable practices by allowing hospitals to pursue innovative financing and procurement strategies.
b) A Policy Implementation Strategy for decarbonisation: Developing and implementing a policy strategy that encourages decarbonisation action in hospitals at hospital level can create a supportive regulatory environment for energy transition initiatives. This may include setting carbon reduction targets, providing incentives for renewable energy adoption, establishing green procurement policies, and incorporating climate resilience measures into healthcare infrastructure planning.
c) Energy Profile Assessment and Baseline Analysis: Conducting an energy profile assessment and baseline analysis of hospital facilities can provide valuable insights into energy consumption patterns, inefficiencies, and opportunities for improvement. By understanding their energy usage and performance metrics, hospitals can identify priority areas for energy efficiency upgrades, renewable energy integration, and operational optimization.

d) Change Management and Theory of Change: Implementing change management principles and a theory of change framework can facilitate the energy transition process by engaging stakeholders, building capacity, and fostering a culture of innovation and collaboration within the hospital community. Change management approaches can help overcome resistance to change, promote buy-in from staff, and ensure the successful implementation of energy efficiency and sustainability initiatives.

e) Private Funding Model for Decarbonisation which involves Implementing a private funding model to invest in their own decarbonisation process can enable hospitals to access capital for energy transition projects without relying solely on public funding or government incentives. Private financing mechanisms such as energy performance contracts, green bonds, or third-party financing arrangements can help hospitals overcome financial barriers and unlock investment in renewable energy infrastructure, energy efficiency retrofits, and sustainable technologies.

Reference List

Akinbami, O. M., Oke, S. R., & Bodunrin, M. O., 2021. The state of renewable energy development in South Africa: An overview. Alexandria Engineering Journal, 60(6), 5077-5093.

Al-Rawi O. F., Yusuf B., Al-Ghamdi S., 2023. Sustainable solutions for healthcare facilities: examining the viability of solar energy systems. Frontiers in Energy Research. Volume 11 – 2023.

Annual Performance Plan, 2016. Department of infrastructure Development. https://provincialgovernment.co.za/department_annual/883/2016-gauteng-infrastructure-development-annual-report.pdf

Annual Performance Plan, 2021. Department of infrastructure Development. https://provincialgovernment.co.za/department_annual/2021-gauteng-infrastructure-development-annual-report.pdf

Altieri, K. E., Stone, A., 2016. Prospective air pollutant emissions inventory for the development and production of unconventional natural gas in the Karoo Basin, South Africa. Atmospheric Environment 129, 34–42.

Attia, S., 2018. Roadmap for NZEB Implementation, (Ed.), Net Zero Energy Buildings (NZEB), Butterworth-Heinemann, Oxford, pp. 343–369.

Baxter, P., & Jack S., 2010. Qualitative case study methodology: Study design and implementation for novice researchers. Qualitative Report. 13. 10.

Bischof-Niemz, T., Creamer, T. 2019. South Africa's energy transition: a roadmap to a decarbonized. Low-cost and job-rich future. First ed. New York, NY: Routledge.

Borel-Saladin, J. M. & Turok, I. N., 2013. The impact of the green economy on jobs in. South African Journal of Science, 109(4), 1-2.

Bowen, G. A., 2009. "Document Analysis as a Qualitative Research Method". Qualitative Research Journal, 9 (2), 27–40. https://doi.org/10.3316/QRJ0902027 [Accessed 06 August 2022].

Boyce, C., and Neale, P., 2006. Conducting in-depth interview: A guide for designing and conducting in-depth interviews for evaluation input. Pathfinder International Tool Series, Monitoring and Evaluation.

Burnett, S., Mendel, P., Nunes, F., Wiig, S., van den Bovenkamp, H., Karltun, A., 2016. Using Institutional Theory to Analyse Hospital Responses to External Demands for Finance and Quality in Five European Countries. Journal of Health Services Research & Policy, 21, 109-117.

Carbon Tracker Initiative, 2020. https://carbontracker.org/reports/ [Accessed 29 June 2022]

Cherp A., Vinichenko V., Jewell J., Brutschin E., Sovacool B., 2018. Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Research & Social Science, 37, 175-190.

Cunningham, A., 2015. "Designing energy efficient hospitals? First, let us give you the facts on existing performance", Western Cape Government Health Department: Sandton, South Africa, 2015.

Daramola O., 2020. A Review of Combined Heat and Power Systems for Hospitals Applications. International Journal of Scientific & Engineering Research 11 (11), 312-317.

Davey T., 2016. Developing Countries Cannot Afford Climate Change. 5 August 2016. Internet: https://futureoflife.org/2016/08/05/developing-countries-cant-afford-climate-change. [Accessed 13 July 2022]

De Lille, P., (2022 September 29). Briefing by the Minister of Public Works. https://www.gov.za/speeches/minister-patricia-de-lille-briefing-request-information-process-pv-and-water-savings [Online] [Accessed 29 September 2022].

Department of Public Works and Infrastructure, 2022. Integrated Renewable Energy Resource Efficiency Project Information https://www.irerep.co.za/about/ [Accessed 20 March 2024].

DMRE (Department of Minerals and Energy) 2003. White paper on renewable energy. Pretoria. www.dmre.gov.za.

DMRE (Department of Minerals and Energy) 2003. White paper on renewable energy. Pretoria. www.dmre.gov.za.

Duindam, D., 2022. Transitioning to Sustainable Healthcare: Decarbonising Healthcare Clinics, a Literature Review" Challenges 13, no. 2: 68. https://doi.org/10.3390/challe13020068 [Accessed December 2023]

Entrop, B., Brouwers, H., 2009. Assessing the sustainability of buildings using a framework of triad approaches. Journal of Building Appraisal 6, 26-28.

Energy Chamber, 2023. The State of South African Energy.

Eyre D. J., 2023. Value in use assessment for thermal coal in The Coal Handbook (Second Edition),

Ferris N., (August 14, 2023). Weekly data: South Africa's unprecedented rooftop solar boom. https://www.energymonitor.ai/tech/renewables/weekly-data-south-africas-unprecedented-rooftop-solar-boom/ [Accessed February 2024].

Fraile, J. S., San-José, J., González-Alonso, A., 2014. A Boiler Room in a 600-Bed Hospital Complex: Study, Analysis, and Implementation of Energy Efficiency Improvements. Energies, 7, 3282-

Fraile, J., 2014. A Boiler Room in a 600-Bed Hospital Complex: Study, Analysis, and Implementation of Energy Efficiency Improvements. Energies, 7(5), 3282-3303.

Furner, Nicholas & Green, Donna & Koskinen, Ilpo & Lipson, Mathew & Baldry, Mark & Maddocks, Andrew & Menictas, Chris & Noack, Jens & Moghtaderi, Behdad & Doroodchi, Elham. 2020. Healthy Power: Reimagining Hospitals as Sustainable Energy Hubs. Sustainability. 12. 8554.

Furner, Nicholas & Green, Donna & Koskinen, Ilpo & Lipson, Mathew & Baldry, Mark & Maddocks, Andrew & Menictas, Chris & Noack, Jens & Moghtaderi, Behdad & Doroodchi, Elham. 2020. Healthy Power: Reimagining Hospitals as Sustainable Energy Hubs. Sustainability. 12. 8554.

Fusheini A., and Eyles J.,2016. The Social Determinants of Health and the Role of the Health Care System: A Case Study of the Significance of Good Governance in Public Hospitals in South Africa. Health 8 (12).

Fuso Nerini, F., Sovacool, B., Hughes, N. 2019. Connecting climate action with other sustainable development goals. Nature Sustainability 2(8), 674-680.

Glushkov, D., & Paushkina, K., Kristina & Vershinina, K., & Olga V., 2022. Slagging characteristics of a steam boiler furnace with flare combustion of solid fuel when switching to composite

Goldthau, A., Eicke L., and Weko, S., 2020. The Global Energy Transition and the Global South. In Hafner M. and Tagliapietra S. (eds) 319 -339. Springer Nature, Lecture Notes in energy.

Gurieff, N., Green, D., Koskinen, I., Lipson, M., Baldry, M., Maddocks, A., Menictas, C., Noack, J., Moghtaderi, B., & Doroodchi, E., 2019. Healthy Power: Reimagining Hospitals as Sustainable Energy Hubs. Sustainability, 12(20), 8554.

Harish, V., & Kumar, A. 2016. A review on modeling and simulation of building energy systems. Renewable and Sustainable Energy Reviews. 56. 1272-1292.

Hassan, Qusay Algburi, Sameer Sameen, Aws Zuhair Salman, Hayder Jaszczur, Marek M.A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications

Hernandez R., Jordaan S., Kaldunski B., and Kumar N., 2020. Aligning Climate Change and Sustainable Development Goals with an Innovation Systems Roadmap for Renewable

Hernandez R., Jordaan S., Kaldunski B., Kurmar N., 2020. Aligning Climate Change and Sustainable Development Goals with an Innovation Systems Roadmap for Renewable Power. Front sustain.

Hohne, P. A., Kusakana, K., & Numbi, B. P., 2019. Improving Energy Efficiency of Thermal Processes in Healthcare Institutions: A Review on the Latest Sustainable Energy Management Strategies. Energies, 13(3), 569.

Hohne, P. A., Kusakana, K., and Numbi, B.P. 2020. Improving Energy Efficiency of Thermal Processes in Healthcare Institutions: A Review on the Latest Sustainable Energy Management Strategies. Energies, 13(3):569, 2-28.

Hossain F., 2019. Coal-Fired Boiler, Chapter Three - Energy, Sustainable Design and Build, PP 67-135.

Low Emission Strategy 2020. https://www.dffe.gov.za/sites/default/files/docs/2020lowemission_developmentstrategy.pdf [Accessed 10 September 2022]

Hussain, S. T., Lei, S., Akram, T., Haider, M. J., Hussain, S. H., & Ali, M. 2018. Kurt Lewin's change model: A critical review of the role of leadership and employee involvement in organizational change. Journal of Innovation & Knowledge, 3(3), 123-127.

IEA, 2019. Sustainable Development Scenario, World Energy Outlook. International Energy Agency. Available online at: https://www.iea.org/reports/world-energy-model/sustainable-

2022].

IEA, 2013. World Energy Outlook, Golden Rules for a Golden Age of Gas. https://www.iea.org/reports/golden-rules-for-a-golden-age-of-gas [Accessed 17 June 2022]

IEA, 2019. Energy RD& D Online Data Service. International Energy Agency. Available online at: http://www.iea.org/statistics/RDDonlinedataservice [accessed 18 July 2022].

IEA, 2019. World Energy Outlook. Paris: International Energy Agency. https://www.ea.org/reports/world-energy-outlook-2019 (Accessed 17 June 2022).

IEA, 2020. Renewables: analysis and forecast to 2050. Paris, OECD/IEA. https://www.iea.org/reports/world-energy-outlook-2020 (Accessed 20 June 2022).

IRENA .2019. Renewable Capacity Statistics 2019. International Renewable Energy Agency Available online at: http://irena.org//media/Files/IRENA/Agency/Publication/2018/Mar/IRENA_RE_Capacity_Statistics_2018.pdf. [Accessed October 4, 2022].

IREREP. 2021. https://www.irerep.co.za

Ivanovski, P., and Marinucci N., 2021. Policy uncertainty and renewable energy: Exploring the implications for global energy transitions, energy security, and environmental risk management Energy Research & Social Science. 82, 102415

kinbami, O., Oke, S., Bodunrin M., 2021. The state of renewable energy development in South Africa: An overview. Alexandria Engineering Journal. 60 (6) 5077-5093.

Kohan, A. L. & Spring, H. M., 1991. Boiler Operations Guide. 3rd ed. New York: McGraw-Hill.

Kohan, A. L. & Spring, H. M., 1991. Boiler Operations Guide. 3rd ed. New York: McGraw-Hill.

Kolokotsa, D., Rovas, D., Kosmatopoulos, E, and Kalaitzakis, K. 2011. A roadmap towards intelligent net zero- and positive-energy buildings. Solar Energy, 85 (12), 3067-3084.

Kras, I. 2011. Sustainable hospital buildings. MSC Real Estate and Housing. Technical University of Delft, Netherlands.

Krumal, K., Mikuska, P., Horak, J., Hopan, F., and Kubonov, L., 2021. Influence of boiler output and type on gaseous and particulate emissions from the combustion of coal for residential heating. Chemosphere, 278, 3-9.

Li H., 2018. Coal-fired Utility Boiler Operation Factors Analysis and Optimization Measures. IOP Conference Series: Earth and Environmental Science170 (4),1755-1315

Maassen W., 2019. Evaluation Dutch preliminary nZEB requirements for hospital and university buildings DOI, 111 03033.

MacKinnon, M. A., Brouwer, J., and Samuelsen, S. 2018. The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration. Progress in Energy and Combustion Science, 64, 62 -92.

Malek, M. A., 2007. Heating Boiler Operator's Manual: Maintenance Operations and Pepairs. 1st ed. New York: Mcgraw - Hill Maintenance

Mariano-Hernández D., Hernández-Callejo., L. Zorita-Lamadrid., A. Duque-Pérez., O and Santos García F., 2021. A review of strategies for building energy management system: Model predictive control demand side management, optimization, and fault detect & diagnosis. Journal of Building Engineering, 33, 1-12.

Mayne, John. (2015). Useful Theory of Change Models. Canadian Journal of Program Evaluation. 30. 10.3138/cjpe.30.2.142.

McGain, F., and Jodi S., 2016. Environmental Sustainability in Anesthesia. Advances in Anesthesia. 34. 47-61.

Morgenstern, P., Raslan R., and Ruyssevelt., P., 2016. Understanding hospital electricity use: an end-use(r) perspective. 9, PP 2-15.

Mouton, J., 2000. How to succeed in your Master's & Doctoral Studies: A South African guide and resource book. Van Schaik, Pretoria, 44-61.

NDoH, 2012. National Health Act, 2003: Policy on the Management of Hospitals. Government Gazette, Department of Health, Pretoria.

Nerini, F., Sovacool, B., Hughes, N., Cozzi, L., Cosgrave, E., and Howells, M., 2019. Connecting climate action with other sustainable development goals. Nature Sustainability. 2, 674–680.

Neuman, W.L., 2014. Basics of Social Research: Qualitative & Quantitative Approaches.3rd ed. United States, Pearson Limited.

O'Leary, Z., 2004. The essential guide to doing research, London. Sage Publications, First Edition.

Omer, Y., & Roberts, T., 2022. A novel methodology applying practice theory in pro-environmental organizational change research: Examples of energy use and waste in healthcare. Journal of Cleaner Production, 339, 130542.

Paina, L., Wilkinson, A., Tetui, M., 2017. Using Theories of Change to inform implementation of health systems research and innovation: experiences of Future Health Systems consortium partners in Bangladesh, India and Uganda. Health Research Policy System 15, 109. https:

Painuly, J., 2001. Barriers to renewable energy penetration; a framework for analysis. Renewable Energy, 24(1), 73-89.

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. Administration and Policy in Mental Health, 42 (5), 533.

Porto, T., C. 2020. Towards zero energy hospital buildings: Energy savings through central steam systems analysis and alternative humidification scenarios. MSC Architecture Building and Planning, Eindhoven University of Technology, Netherlands.

Pretorius I., Piketh S. J., and Burger, R., 2015. The impact of the South African energy crisis on emissions. Transactions on Ecology and the Environment. 198, 255-264.

REN21, 2020. Renewables 2020 Global Status Report (Paris: REN21 Secretariat) https://www.ren21.net/wp-content/uploads/2019/05/gsr_2020_full_report_en.pdf [Accessed 18 July 2022].

Renjitha T., and Samuel D., 2021. Going Green: Challenges Hindering Adoption of Green Practices in Hospitals 1 (1), Amity Journal of Professional Practices.

Rompco. 2020. Rompco Historical Milestones. Available: https://www.rompco.co.za/historical-milestones [2020, September 20].

Rubin, H.J., and Rubin, I.S., 1995. Qualitative Interviewing: The art of hearing data. 2nd Edition, Sage Publications, London.

Rutledge, P., & Lynn H., 2020. In-Depth Interviews. Pp 1-7.

Safari, A., Das, N., Langhelle, O., Roy, J., Assadi, M. 2019. Natural gas: A transition fuel for sustainable energy system transformation? Energy Science and Engineering, 7, 1075–1094.

Sakellariou D., Rotarou E.S., 2017. The effects of neoliberal policies on access to healthcare for people with disabilities. International Journal Equity Health. (1), 199.

Sarkar, D. K., 2015. Thermal Power Plant : Design and Operation. 1st ed. Amsterdam: Elsevier.

Schneider, H., Barren, P. and Fonn, S., 2007. The Promise and the Practice of Transformation in South Africa's Health System. In: Buhlungu, S., Daniel, J., Southall, R. and Lutchman, J., Eds., State of the Nation: South Africa 2007, HSRC Press, Cape Town, 289.

Shen, C., Zhao, K., Ge, J., & Zhou, Q., 2019. Analysis of Building Energy Consumption in a Hospital in the Hot Summer and Cold Winter Area. Energy Procedia, 158, 3735-3740.

Sintayehu D., 2018. Impact of climate change on biodiversity and associated key ecosystem services in Africa: a systematic review. Ecosystem Health and Sustainability ecosystem health and sustainability. 4(9), 225–229.

Sithole, H. 2016. The Electricity Generation Infrastructure Transition to 2050: A Technical and Economic Assessment of the United Kingdom Energy Policy. Unpublished Research Report, Ph.D. Mechanical Engineering, The University of Sheffield, United Kingdom.

Sobota, T., 2018. Improving Steam Boiler Operation by On-Line Monitoring of the Strength Improving Steam Boiler Operation by On-Line Monitoring of the Strength and Thermal Performance. Heat transfer engineering, 39(13), pp. 1260,1261,1268.

South Africa's Low Emission Development Strategy 2050. 2020. https://www.dffe.gov.za/sites/default/files/docs/2020lowemission_developmentstrategy.pdf [Accessed 2 June 2022]

South Africa's Low Emission Strategy 2050. 2020.

Srinivas G.D., Kumar D. R., Mohan P., and Rao B., 2017. Efficiency of a Coal Fired Boiler in a Typical Thermal Power Plant. American Journal of Mechanical and Industrial Engineering, 2(1), 32–36.

State of energy in South African cities, 2020. https://www.sustainable.org.za/index.php [Accessed 28 June 2022].

Stauss, T., 2017. Steam Handbook. 1st ed. Reinach: Endress + Hause

Strambo et al., 2019. The end of coal? Stockholm: SEI

Strambo, C., Burton, J. and Atteridge, A. 2019. The end of coal? Planning a "just transition" in South Africa. Stockholm Environment Institute, 1–19.

Swilling M., and Annecke E., 2012. Just Transitions: Exploring Sustainability in an Unfair World CT Press & United Nations University Press.

Talwekar A., 2023. Boiler Operation: An In-Depth Technical Analysis

The Republic of South Africa. 2001. The South African Climate Change Response Strategy. http://www.climateresponse.co.za/home/gp/1 [accessed 1 June 2022]

Tiwari A. K., Chatterjee K., Agrawal s., and Singh G.K. 2023. A comprehensive review of photovoltaic-thermal (PVT) technology: Performance evaluation and contemporary development. Energy Reports, 10 (1) ,2655-2679.

Turok, I., Borel-Saladin, J. 2014. Is urbanization in South Africa on a sustainable trajectory? Development Southern Africa 31 (5), 675-691.

United Nations Commission on Environment and Development (1987). Our common future. [online] United Nations Commission on Environment and Development, p.15. Available at: https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html [Accessed 26 Jul. 2022].

Vamvuka, D., 1999. Environmental Impacts of Coal Utilization on the Ecosystem. Energy Exploration & Exploitation.

Von Holdt, K., 2010. Nationalism, Bureaucracy and the Developmental State: The South African Case. South African Review of Sociology, 41, 4-27.

Vourdoubas, L. (2022). Possibilities of using sustainable energy technologies in hospitals including CHP systems, solar photovoltaics, and heat pumps. European Journal of Energy Research 2 (2), 1-9.

Wang C., Liu Y., Zheng S., Jiang A., 2018. Optimizing combustion of coal-fired boilers for reducing NOx emission using Gaussian Process, Energy, 153, Pages 149-158.

Weimann, E., Patel, E. 2017. Tackling the climate targets set by the Paris Agreement (COP 21): Green leadership empowers public hospitals to overcome obstacles and challenges in a resource-constrained environment. SABINET African Journals, 107 (1), 34-38.

Woodruff, E. B. & Lammers, H. B., 1977. Steam Plant Operations. 4th ed. New York: McGraw-Hill.

World Cities report. 2020. The Value of Sustainable Urbanisation. United Nations Human Settlements Programme (UN-Habitat).

Zhang, K., Zhang, Y., Guan, Y., & Zhang, D., 2012. Boiler design for ultra-supercritical coal power plants. Ultra-Supercritical Coal Power Plants, 104-130.